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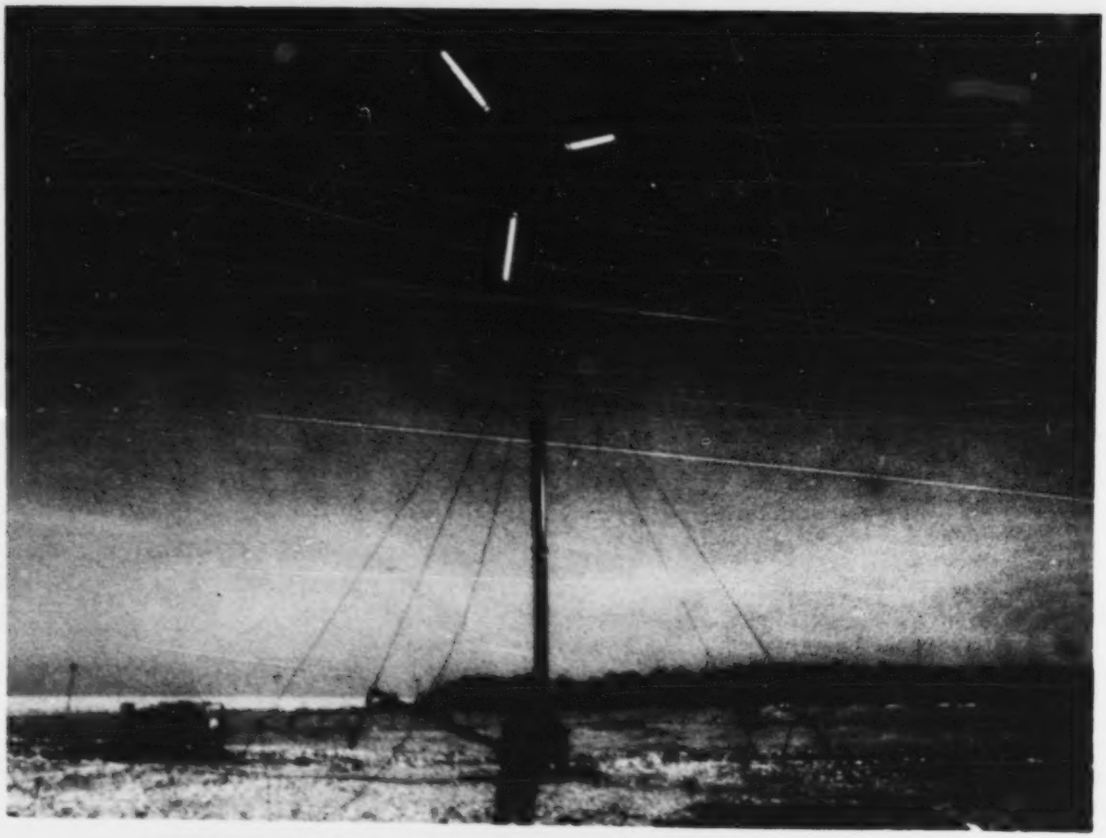
6th Annual

Wind Energy Symposium

November 7th, 1983
Toronto Canada



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6TH ANNUAL WIND ENERGY SYMPOSIUM
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PROCEEDINGS
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NOVEMBER 7TH, 1983

The Sheraton Centre
Toronto, Canada

EDITOR:

Nicholas J.M. Teekman, B.Sc.
DynamoGenesis Inc.

These proceedings are a record of the 'state of the art' in 1983 of international research, test, development and planning methodologies and HAWT/VAWT industrial WECS technology. It is published as a public service for the information of the public.

6TH ANNUAL WIND ENERGY SYMPOSIUM

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OPENING REMARKS

Welcome to the 6th Annual Wind Energy Symposium here at the Sheraton Centre. On behalf of the DynamoGenesis Corporation I would like to welcome you to the event. To get things rolling right away, I would like to introduce to you the Chairman, Mr. Fred Schwartz, from the Ontario Ministry of Energy. Fred.

Thank you, Nicholas. It is really encouraging to see the group of people that is here today. We have an ambitious event ahead of us and I am going to try to keep things moving along according to schedule. If we at all can. There will be time in between the presentations for questions and I hope people are really active in that regard. Basically, the first thing I have to do is to thank Nicholas and all of the people of DynamoGenesis who have put this event together. It would not have happened without them, nor would the previous Wind Symposium events that have been held. This is the Sixth. I am really pleased to assist in terms of Ministry assistance and to be here today with you all. So without much further ado, I will introduce our first speaker.

ATLANTIC WIND TEST SITE - AN UPDATE REPORT

November 7th, 1983
Malcolm A Lodge, P. Eng.
Resource Ventures Inc., P.E.I.

ABSTRACT

The Atlantic Wind Test Site (AWTS) is a national facility to facilitate research, development, testing and demonstration of wind energy technology and equipment in Canada. Since its opening in July 1980, the AWTS has worked on wind energy technology projects sponsored by both private and government clients and the National Research Council (NRC). A listing and description of completed, current and planned projects is given.

1. INTRODUCTION

The Atlantic Wind Test Site (AWTS) at North Cape, Prince Edward Island has been created by the Goverments of Prince Edward Island and Canada to facilitate research, development, testing and demonstration of wind energy technology and equipment in Canada. The laboratory facilities are located in a harsh but typical coastal environment in the Gulf of St. Lawrence where the effect of a full range of climatological and meteorological conditions on wind energy conversion systems can be observed and measured. The machines get a good workout. A high speed microprocessor based computerized data acquisition and control system is used to carry out investigations of performance.

There are about 100 acres of cleared land and 600 to 800 acres not yet cleared. Presently, there are five machines on the site, including a 500 kW Darrieus from DAF Indal Ltd.

The AWTS was designed and developed by the Institute of Man and Resources (IMR) under the 1977 Canada-P.E.I. Agreement on Renewable Energy Development and was officially opened for business in July 1980. The facility is managed by IMR under the terms of a long-term operating agreement with the National Research Council.

Resource Ventures Incorporated, a wholly owned subsidiary of the Institute of Man and Resources, provides staff and management to operate the site as the agent for IMR.

2. FUNDING

The AWTS obtains operating funds from both paying clients and users of the site's resources and from the National Research Council, Energy Project through a contribution agreement. The contribution agreement provides a contribution of up to $200,000/year to help offset operating costs. The agreement has a ten-year term and is managed by five directors, three named by the NRC and two by IMR. The directors meet quarterly to review operations and to provide guidance for new development and activity.

3. PROJECTS

Most of our work is the testing of wind turbines and related technology. Projects to date are funded by government demonstration programs and individual department demonstration programs.

The projects listed below are organized in chronological order, more or less. Project numbers are for internal AWTS reference and should be referenced when corresponding or requesting information. A list and their availability may be obtained by contacting the author.

3.1 Performance and Reliability Testing of a 1 kW Bergey Wind Turbine. (Project # 29.06)

Sponsor: Internal AWTS Investigation
Status: Report available - Testing continuing
Summary: A 1 kW Bergey wind turbine has been evaluated. The machine was planned for use as a battery charger for emergency back-up to an aquaculture tank aeration system. Reliability of the system was evaluated and a report prepared describing failure of the machine's original aluminum blades. Quite a successfull machine in the U.S. Recently had a tail pin failure.

The manufacturer has subsequently changed the material and the configuration of the blades and operation and testing is proceeding.

3.2 Study of the Relationship Between Standard AES Wind Velocity Measurements, Ice Accretion and Power Output from a Wind Turbine Mounted at a 10 m Hub Height. (Project # 40.02)

Sponsor: Department of Environment, Atmospheric Environment Service
Status: Complete - Report available
Summary: A study was initiated at AWTS in cooperation with the Atmospheric Environment Service of Canada (AES) to measure and record the energy produced by a representative WECS located adjacent to standard anemometers used by AES. A Rosemount ice accretion monitoring device is mounted adjacent to the anemometers and WECS to measure quantity and rate of ice accretion in the area. Data from the anemometer, ice accretion measuring device and the WECS are correlated to determine the effects of icing on performance of WECS and anemometers. The AES has been monitoring wind speed and direction at numerous sites across Canada for many years using standard U2A and 45B anemometers. The anemometers, ice accretion detector, and wind

turbine are located at 10 meter height and spaced approximately 10 meters from each other.

A 2 kW Dunlite wind turbine was chosen as a representative WECS.

3.3 Performance Investigations on a 17m x 11m DAF Darrieus 35 kW Rating. (Project # 52.01)

Sponsor: National Research Council
Status: Complete - Report available
Summary: The AWTS in cooperation with the National Research Council of Canada undertook a study to determine the effects on performance of speed limiting spoiler mechanisms on a 17m x 11m VAWT. Methods of reducing the drag coefficient of the spoiler system in the undeployed position were investigated. Investigations were also carried out to determine the feasibility of using an alternator and static frequency converter to enable the machine to run in a variable speed, variable frequency mode to attempt to achieve improved energy production.

The research and test machine belongs to a school board that had it on the roof of their building After a few years of concern, they gave it to us to get it out of their hair.

3.4 Retrofit and Performance Evaluation of a DAF Indal 6m x9m, 7 kW VAWT. (Project # 29.02)

Sponsor: Energy, Mines and Resources Canada
Status: Complete - Report available
Summary: This machine was initially designed to supply hydraulically generated heat energy for a greenhouse space heating application. To modify this machine to a utility connected wind driven induction generator required removal of the hydraulic system and design of an electric generator/drive train system. The turbine has been rebuilt and installed and has been tested to determine performance and operational characteristics.

Particular attention was paid to obtaining a cost-effective drive train design. The choice was a in-line, induction motor/generator/helical gearbox combination with reduced voltage start control. An integral electrically actuated fan cooled disc brake is mounted on the high speed generator shaft. An operating speed of 137 rpm was chosen. A drive train modal analysis indicated that no significant resonances should be expected at any of the drive train natural frequencies.

Once again, used primarily for research projects rather than as a practical operating machine. Recently had a failure in this one. The upper portion of the blade between the strut and rotor top failed due to fatigue. Now have additional blades and are repairing it.

3.5 Performance and Reliability Testing of a Wellington Wind Power 10 kW HAWT. (Project # 40.03)

Sponsor: Ontario Ministry of Energy and Wellington Wind Power
Status: Testing continuing
Summary: The Ontario Ministry of Energy has purchased a 10 kW HAWT from Wellington Wind Power in Wellington, Ontario. First machine built in Jerry Ball's machine shop in 10 kW size. The machine is being tested and evaluated for Wellington Wind Power at the AWTS prior to its installation as a demonstration unit at Kortwright Centre near Toronto.

The machine has a three-bladed, 9.1m diameter rotor with pitch control. The output is used to charge batteries at 110V and to provide up to 9 kW of space or water heating. A fan tail rotor is used for yaw control. The tail rotor assembly can be manually deflected from the ground to enable shut down for servicing.

The machine was installed on a 60 foot self-erecting tower in February of 1983 and will be installed at Kortright in September of 1983, after the six to eight month performance curve testing of the machine is completed.

3.6 Performance Testing of a Windstar WS-482-4 (Project # 40.05)

Sponsor: Renewable Dynamics Inc.
Status: Complete - Report available
Summary: Performance testing of this small HAWT commenced in August 1982 and was completed in October, 1982. The machine is rated by the manufacturer at 250 watts and has a rotor diameter of 1.2 m. A permanent magnet 3 phase alternator is driven directly by the rotor.

3.7 Anemometer Comparison. (Project # 40.04)

Sponsor: Department of the Environment, Atmospheric Environment Service, through a contract with NRC.
Status: Site prepared and prior test calibration of anemometers complete.
Summary: The performance of twenty different types or models of anemometers and associated recording, data logging and display devices will be measured. The units will first be calibrated in the AES wind tunnel and then erected at the AWTS for a year of field evaluation. They will then be removed and retested in the wind tunnel. Records of the before and after tests will be compared along with data from the field tests to indicate long term accuracy, reliability and performance.

We have had problems with wind speed measurement from anemometers, a serious concern because we base all our WECS performance estimates on them. Last week we were working on some joint testing of machines with Pellworm. We learned one of the anemometers we had been basing our analysis on was faulty by 15%. A large problem when you consider that power is proportional to the cube of windspeed.

3.8 WECS Rotor Stress Monitoring and Telemetry. (Project # 40.07)

Sponsor: National Reseach Council
Status: Design completed, testing commenced
Summary: A project to develop a system to measure and record rotor dynamic loads and stresses is being carried out for NRC. A system will be designed and developed that enables measurement with strain gauges, accelerometers, torque transducers and other devices mounted directly on a rotor shaft. A twelve-channel high speed telmetry system will be the link between the rotor and a remote, stationary data acquisition system.

3.9 Investigation and Examination of Procedures to Measure and Process WECS Performance Data. (Project # 40.06)

Sponsor: National Research Council
Status: Investigations complete, report available in September, 1983.
Summary: The objectives of this project are to investigate averaging and method of bins techniques to process WECS performance data and to survey and study relevant literature and the experience of European and U.S. investigators.

A recommended technique is being developed and tested for consideration by CSA for inclusion in WECS performance standards.

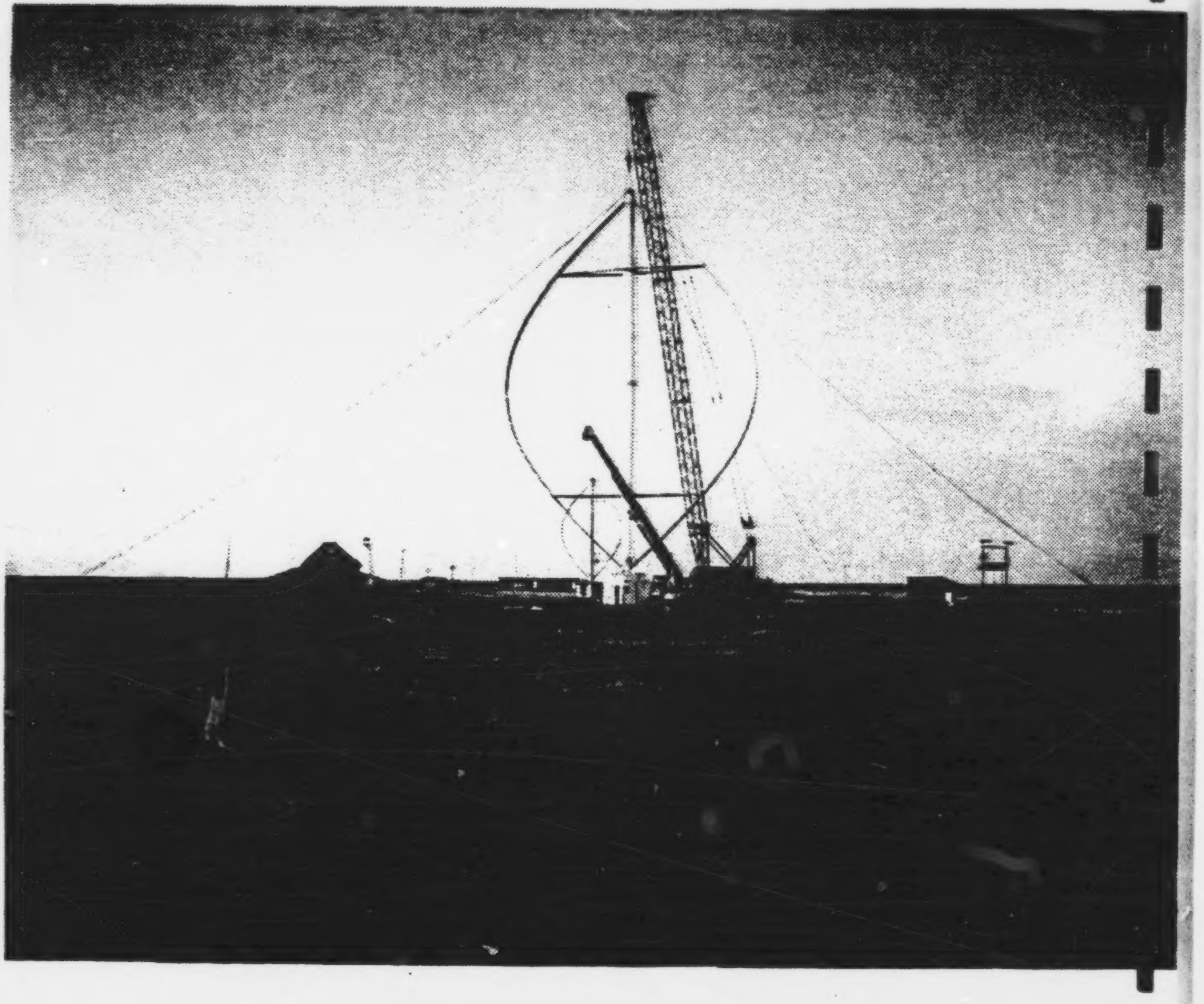
3.10 Northwind L-16 Performance Testing. (Project # 50.08)

Sponsor: Health and Welfare Canada
Status: Machine being installed.
Summary: Health and Welfare Canada, Health Services and Facilities Branch has undertaken a project to demonstrate a L-16 Northwind WECS at a nursing station in Hall Beach, N.W.T. This site is as far north in the arctic that you can get on Canada's mainland, a very severe environment. The machine is being tested at the AWTS prior to shipment to Hall Beach to prove performance and reliability and to demonstrate operational characteristics.

It is a two bladed, variable pitch, synchronous, grid coupled machine. The machine was erected in winds gusting to 45 kts. It was initially tested in 3 phase but is now being tested in single phase which is how it will run in the arctic.

3.11 AQUILO [Roman: The North Wind]. (Project # 50.22)

Figure 1



Sponsor: National Research Council and DAF Indal
Status: Project commencing
Summary: The AWTS is installing and testing a 500 kW VAWT manufactured by DAF Indal of Mississauga, Ontario. The machine has been purchased by NRC from DAF on a turn-key basis. AWTS is installing the machine under contract to DAF and will carry out

1-2 years of testing on behalf of NRC. The rotor and other major components of the machine are fully instrumented to obtain dynamic structural data.

This project was started in early September. Assembly requires two and a half men working for two weeks. At this time the machine is now ready to erect. Commissioning awaits the replacement of modified jaws to couple the rotor to the power module. This job was finished yesterday, we will be commissioning the unit in a few days.

3.12 AWTS/Pellworm Technology Exchange. (Project # 40.14)

Sponsor: National Research Council
Status: AWTS visit complete. The visit report and technical report available September, 1983.
Summary: Under the terms of an international agreement for technology exchange between Canada and Germany, a senior staff member of the AWTS has be able to participate directly in performance testing of a small WECS at the German test station at Pellworm. During the visit the AWTS member attended the Third International Meeting of Test Stations and visited test sites at Riso in Denmark and at Petten in the Netherlands.

3.13 CSA Standards Development. (Project # 50.11)

Sponsor: Internal project
Status: Continuing
Summary: Senior staff of the AWTS are involved in assisting the Canadian WECS community to develop standards for the manufacture, testing and safe application of WECS in Canada. The standards development program is funded by the National Research Council and is assisted by the AWTS and other interested industry, research, utility and consumer groups.

4. CONCLUSIONS

During the three years since its establishment, the AWTS has become a major resource able to assist and encourage the Canadian WECS industry. During this period the site has obtained much of the equipment and developed many of the skills and much of the expertise necessary to install and test WECS effectively and efficiently. As outlined earlier many projects have been completed and several new and exciting projects are in progress. Manufacturers and users of new WECS technology have recognized the need for thorough testing and evaluation of performance and reliability before committing themselves to the major capital outlays and risk involved in producing or purchasing machines. The AWTS is able to respond to this need and to react quickly to requests for information and assistance from the WECS industry.

For information regarding terms and conditions of site use, rates and fees for professional assistance and consulting and for quotes and estimates for testing work please contact the author.

QUESTIONS:

Q. When you discovered that your anemometer was off by 15%, how did you go back and adjust your performance measurements?

A. We just throw that data out. When we recognize an error in our instrumentation like that, it's a matter of repeating the test. There is no way to predict the degradation of the anemometer. We are now instituting a policy and procedure on the site as quickly as we can to take all of the anemometers that are in use, log their data on a daily basis and do a regression analysis amongst all of the anemometers to determine which one(s) have gone outside an acceptable band of performance. In that way it flags it for us so we can take it out of service and see what the problem is. We'll be doing this with all of the AES anemometers as well. We'll have quite a large volume of data to crunch every day but our machine is quite able to do that.

Q. How long does it take you to get a report on a power curve out? How does a private manufacturer go about getting a test bed site?

A. It depends on the season, but at this time of year we can produce a power curve in a couple of weeks. Generally, we have persistant enough winds over a wide enough range at this time of year to give us a power curve from zero to 15 or 20 m/s. We have a little trouble sometimes at the upper end, but we can get the operating range of most machines in a few weeks. Concerning the second question, we are a private agency, I have some brochures and prospectus with me containing our rates, terms and conditions. A manufacturer or any agency who would wish to make use of our site can contact us. We generally work on the basis of estimates and a contract for either a firm price or a ceiling price to produce the information desired. Just like going to your doctor or lawyer.

Q. What is the nature of your CSA work?

A. The AWTS has not performed any CSA testing to date. Our CSA work is to attempt along with the rest of the industry to produce standards. We hope that when the standards are developed that we will qualify as a testing agency to do field testing of machines. It's been our experience that most of these machines require a little bit of invesigation before they go into production and before they can be accepted.

Q. How is the DAF 500 kW project being funded?

A. The DAF 500 kW project or 'AQUILO' is funded by the National Research Council, I'm sure Marc Chappell will be saying more about this later. Essentially they purchased the machine for testing at our site. We have subcontracted with DAF to put it together for them. Their contract with NRC is to provide the machine 'in situ' and operating. For logistical reasons DAF has chosen us to put the machine together and erect it for them. I don't want to say too much about that project either because Lawrence is going to get up here and tell you more about it.

Field Trials of the DAF Indal Series 6400 Model 500 kW VAWT and the Wind Diesel Hybrid

Lawrence Schienbein, Ph.D., P.Eng.
DAF Indal Ltd.
Mississauga, Ontario

I would like to introduce the presentation this morning by speaking about our commercialization program objectives and our perceived markets. DAF's commercialization objectives are very easily stated. We intend to develop wind turbines as a large commercial business within the company. We perceive two immediate markets for medium to large scale wind turbines: the wind farm market and the wind-diesel market.

DAF Indal became involved with wind turbines in 1974 when we began the manufacture of 6 small machines. In 1975 we initiated a proposal for the Magdalen Island 230 kW machine which was manufactured and put into service in 1977. In 1976 we began the design of a 50 kW series of machines for primarily grid-connected applications. In 1981 we began the detailed design of the 500 kW wind turbine, the first commercial wind turbine offered by the company.

The 50 kW machines have served as very useful technology development vehicles. We have built 14 of these machines and 11 are still in service. Eight of them are grid-connected; four we consider research units. They have accumulated, as of this date, well in excess of 40,000 hours of operation. The 50 kW machine that has the most number of hours is installed in northern California; the machine that has gathered the most kWhs is installed at the Southern California Edison Test Center. We have six machines in Canada. The Churchill machine is the most northerly unit, located near the 60th parallel.

500 kW Vertical Axis Wind Turbine Field Trials

Figure 1 is a photo of the 500 kW machine. The rotor is the same size as that of the Magdalen Island machine. We have used the NACA 0015 profile with a much larger blade chord - 29 inches compared to 24 inches for the Magdalen Islands wind turbine. The rotor weight is about 20 tons.

Figure 2 shows the main features of the 500 kW machine. The rotor obviously has been contracted in this schematic in order to get everything on the same slide. The main features of the machine are the hydraulically supported bull gear driving two generators, the hydraulic lower and upper bearings, three pairs of guys, the hydraulic pivot seat and coupling arrangement, and the tapered column, which is not shown too clearly on this slide. In this machine the bull gear is elevated to a preset position and the variation in guy length is taken up by the upper hydraulic bearing.

The predicted performance of the 500 kW VAWT is shown in Figure 3. The power output reaches 500 kW at about 18 m/s but the power output actually peaks at about 575 kW. The expected efficiency of the machine is about 90% over most of the power producing range.

We will be involved with two test programs over the next 12 months. Unit 001 is now installed and operating at the Southern California Edison test center near Palm Springs. DAF Indal is involved in a joint test program with Southern California Edison Company, with some support from Sandia Laboratories. The commissioning has been completed and preacceptance tests of the machine are practically complete. We will be moving into acceptance testing around the 15th of November. The machine is operating in automatic and is fully operational. The unit 002 rotor is completely assembled on the ground at the Atlantic Wind Test Site and will be erected next week. The unit 002 test program will be handled by the National Research Council and the Atlantic Wind Test Site.

The test program at Southern California Edison Company involves three phases: commissioning, preacceptance and acceptance. The acceptance portion of the testing involves automatic unattended operation of the machine for 1000 hours in cooperation with Southern California Edison. The preacceptance program is designed to check out the machine to make sure all systems are functioning correctly before proceeding with the acceptance tests.

A computer based data acquisition system supplied by Sandia Laboratories has been installed at the site. The system can scan 48 input channels at up to about a 50 Hz sampling rate. The data are recorded on disc and processed at the site using a number of computer programs supplied with the system.

Figure 4 shows actual electrical power output and shaft speed data plotted on the same coordinates with wind speed plotted above. In this particular run the machine actually reached 500 kW and then one of the two overspeed dump valves tripped (because it was set too low). The machine stopped quickly. The power output is seen rising from left to right and then it decreases and becomes negative because the generators stayed on line momentarily while the VAWT was braking. This event occurred early in the commissioning phase. Figure 5 shows the same data in more detail. It demonstrates the power of the computer based data acquisition system to "blow up" data for closer examination. The upper trace with the ripple on it is the power output fluctuating around 500 kW. One can see when the dump valve opens up and the speed drops abruptly.

Figure 6 shows blade stress data from the Southern California Edison machine. This plot shows decaying stress oscillations. These are blade stresses after the machine has come to a stop and are simply a result of the rotor "shaking". The rotor is a very lively structure and it keeps on "shaking" after it has come to a stop. The magnitude of these stresses and the fact that they persisted for a few seconds convinced us that we would have to implement what we call a soft braking system.

Figure 7 shows the capability of the computer to do spectral analyses. This figure shows the results of a spectral analysis of flat-wise stress on the blade. The stress amplitude is plotted for each frequency. Using these plots one is able to confirm natural and forced response frequencies.

Figure 8 illustrates the soft braking technique. On the lower curve is plotted hydraulic pressure. Hydraulic pressure is almost a direct indication of the magnitude of braking for this kind of system. When all of the hydraulic pressure is released the rotor and the guy tension press down on the brake blocks. As the hydraulic pressure is increased, the braking torque decreases. During the first part of braking we allow the brakes to come on full, which means the pressure virtually drops to zero for a couple of seconds. When the generator reaches about 3/4 of full speed we begin to pump the rotor up again, which reduces the braking torque. We pump the pressure back up to 600 psi. In the shaft speed trace on the top you can see the slope change as the pressure returns to about 600 psi. We can then achieve a very soft ending to the braking sequence; this reduces the stresses within the rotor structure at the end of braking.

In summary, commissioning and preacceptance testing of the Southern California Edison machine are essentially completed. We expect to begin acceptance testing around the middle of November. The wind turbine was actually erected around July 29th and developed power for the first time on August 18th. We have achieved power outputs as high as 500 kW. This gives us confidence in the predicted performance of the machine. The wind turbine system protection is extensive and is completely functional.

So far the test results are in very close agreement with the predictions of the computer codes we have been using. The power output performance data is limited so far but it seems to be in fairly close agreement with that predicted.

Wind Diesel Hybrid Field Trials

The Sudbury I work was completed in 1982. Sudbury I was basically a demonstration of a vertical axis wind turbine mechanically assisting a diesel generator. Sudbury II work is underway and I have some preliminary results of the testing, some of which I can pass on to you today. Sudbury II emphasizes stand-alone operation of the vertical axis wind turbine.

The main objective of the Sudbury I project was to demonstrate reliable, automatic operation of a prototype wind diesel system in a northern Canadian climate. Figure 9 shows the system that was tested. The wind turbine assists the primary diesel engine; the second diesel generator unit comes on-line automatically when required and is automatically synchronized. The wind turbine peak output at the shaft is about 30 kW.

The plant was operated against a load demand pattern which changed every 10 minutes. It was scaled from an actual remote community load-demand pattern. The primary diesel has to run all the time as it is the prime mover. The number two diesel is brought on-line to assist it and the dump load is switched on automatically.

Table 1 is a summary of the operating hours and other statistics for the Sudbury I work. We are very pleased with the number of operating hours obtained because the wind did not cooperate. During the tests the average wind speed was well below the long term average for

Sudbury. We chose Sudbury because it has one of the highest long term average wind speeds in Ontario. Nevertheless the wind turbine was on-line for 1418.8 hours, which is a significant fraction of the total operating hours of the plant. Although the ambient temperatures were very low early in the testing, they were not as low as we would have liked for the balance of the work.

Figure 10 is a comparison of the predicted and measured one minute average fuel consumption for the plant. These results show that one can accurately predict the fuel consumption for the plant for a time interval as short as one minute.

Figure 11 is an example of a number of test runs comparing predicted and measured fuel savings for the wind turbine operating with only one diesel generator in operation. You can see that the measured and the predicted performance is reasonably close.

Figure 12 compares the fuel consumption predictions of the energy conversion computer model (which we call PLANT) with actual measured results. PLANT is a probablistic simulation of the wind diesel plant operation over a selected period of time. The agreement between the computer predictions and the measured results are quite good with the wind turbine assisting one diesel. With both diesels in operation, and wind turbine assistance, the computer program does a good job as well.

Figure 13 is an example of actual chart recordings of the operation of the plant with two diesel generators on-line and the wind turbine operating. The demand load is at the point where one diesel would normally shut down. Although the diesel generator units are set up to share shaft load equally, they do not share electrical load equally. Alternator number delivers the electrical power that is developed by the wind turbine. The torque ripple of the wind turbine is relatively pronounced. The current ripple is somewhat attenuated. System frequency is fairly stable. The reason that it is greater than 60 Hz is that the plant was set up to operate with 4% speed droop. Therefore when the diesels are lightly loaded, as they are in this case, the frequency will rise to about 61 Hz. The curve therefore illustrates normal operation, not abnormal operation.

n summary, the Sudbury I results show that the measured and the predicted fuel savings are in close agreement. We consider the configuration tested to be technically sound and ready for commercial application. We determined from the Sudbury I work that it would be desirable to look at configurations where one can operate the wind turbine and shut the diesels down. That moves us into the Sudbury II project.

We know that wind diesel systems which allow the wind turbine to operate by itself, with the diesels stopped, can save significantly more fuel. Furthermore diesel engine life can be extended. Of course most of these savings depend on having a good wind regime.

The objectives of the Sudbury II program are to design, build, test, and evaluate both electrically and mechanically coupled stand-alone arrangements wherein the wind turbine can operate by itself at constant frequency. Figure 14 is a schematic of the electrically coupled stand-alone system which is now being tested. It has operated successfully in winds of 20 m/s with good frequency regulation.

Summary

The DAF Indal series 6400 model 500 kW VAWT is available for commercial applications. One unit is in operation now near Palm Springs. The other unit will be operating this year at the Atlantic Wind Test Site. The DAF Indal 50 kW machines, which I touched on earlier in the presentation, have served DAF Indal well as technology development tools and test beds. Third generation machines of this series are operating reliably.

Wind-diesel hybrid development is continuing aggressively at the Sudbury test site. The Sudbury II program emphasizes wind turbine stand-alone mode demonstration and testing.

Before I close I would like to acknowledge the participation of a number of parties in the Sudbury wind/diesel work. The original project was funded by the Ontario Ministry of Energy, the Department of Energy, Mines and Resources, and DAF Indal Limited. The project managers for the Ministry of Energy were Ontario Hydro, who also provided significant technical review support. The Sudbury II project is being funded by the OME, the NRC and DAF Indal Ltd. The National Research Council provided the wind turbine for the test site.

Figure 1

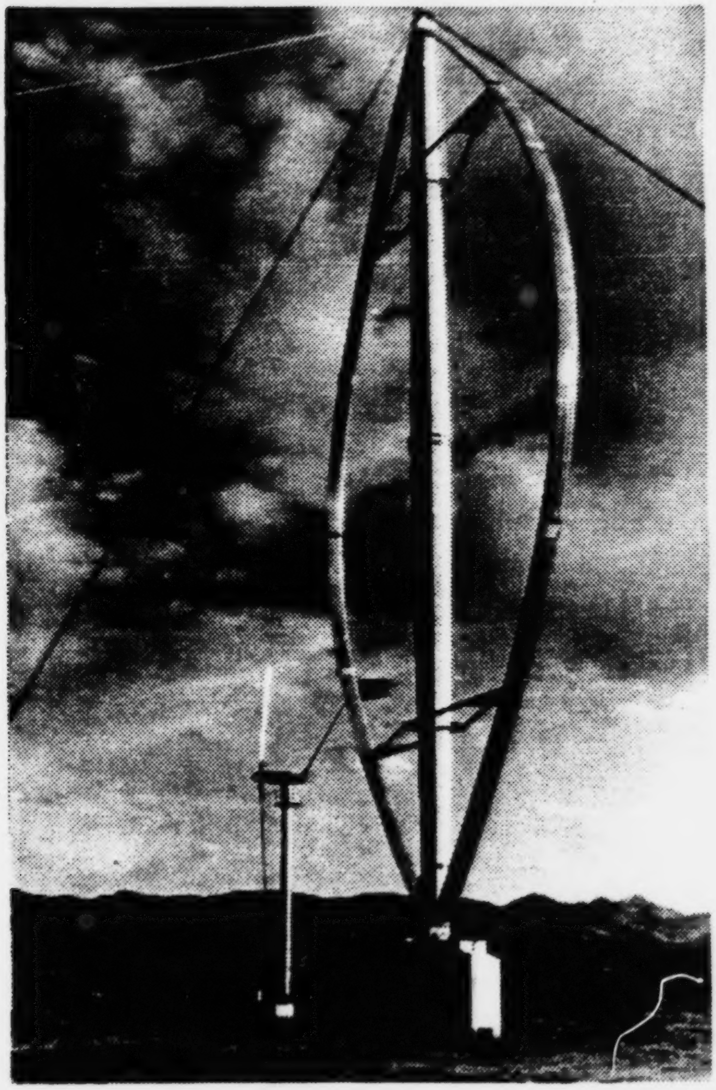


TABLE 1 Accumulated Operating Data for the Period February 12 through September 2, 1982

Elapsed real time for the period	4844	hours
Time that power was supplied to the load	3865.4	hours
Wind turbine generating time	1418.8	hours
Wind turbine idling time (rotor turning but disengaged from the alternator)	349.4	hours
Total wind turbine turning time	1768.2	hours
Wind energy (shaft) supplied to the alternator	11,887	kWh
*Total electrical energy delivered by the system	130,289	kWh
Diesel generator #1 running time	3562.1	hours
Diesel generator #2 running time	1558.2	hours
Total fuel consumption	44,553	liters
Wind turbine starts	311	
Overrunning clutch engagements	6,388	
Ambient temperature range while site was manned	-35°C to 31°C	
Maximum two second average wind speed recorded while the wind turbine was in operation	22	m/s
**Average wind speed for the period March 1st to August 30th, 1982	5.42	m/s

*About 20 hours of data missing due to failure of the instrumentation backup batteries.

**Three weekly averages missing in this period.

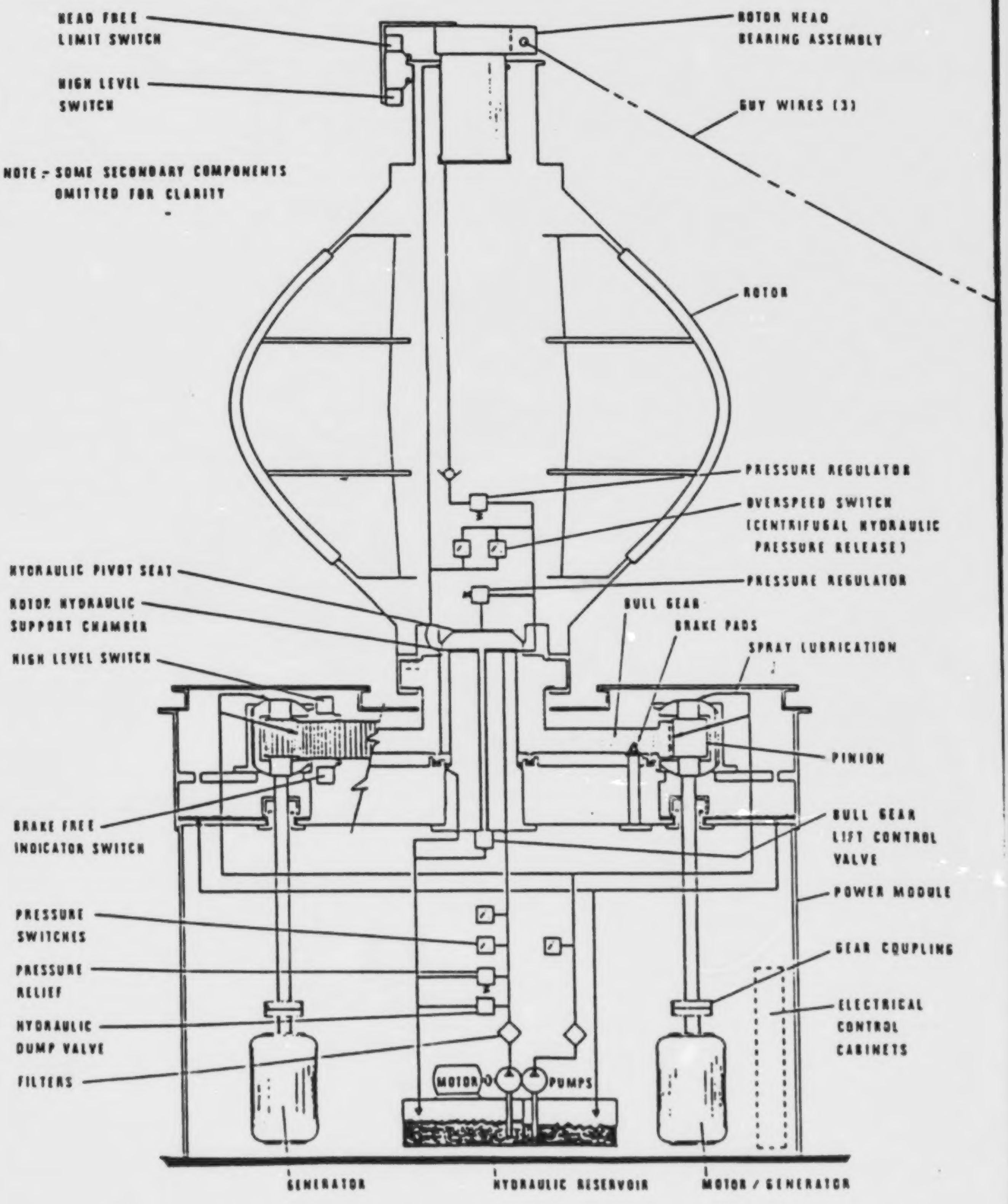

HEAD FREE LIMIT SWITCH
HIGH LEVEL SWITCH
NOTE - SOME SECONDARY COMPONENTS OMITTED FOR CLARITY
ROTOR HEAD BEARING ASSEMBLY
GUY WIRES (3)
ROTOR
PRESSURE REGULATOR
OVERSPEED SWITCH (CENTRIFUGAL HYDRAULIC PRESSURE RELEASE)
HYDRAULIC PIVOT SEAT
ROTOR HYDRAULIC SUPPORT CHAMBER
PRESSURE REGULATOR
BULL GEAR
BRAKE PADS
SPRAY LUBRICATION
HIGH LEVEL SWITCH
PINION
BRAKE FREE INDICATOR SWITCH
BULL GEAR LIFT CONTROL VALVE
POWER MODULE
PRESSURE SWITCHES
GEAR COUPLING
PRESSURE RELIEF
ELECTRICAL CONTROL CABINETS
HYDRAULIC DUMP VALVE
FILTERS
MOTOR
PUMPS
GENERATOR
HYDRAULIC RESERVOIR
MOTOR / GENERATOR

Figure 2 Series 6400 Model 500 kW VAWT Schematic

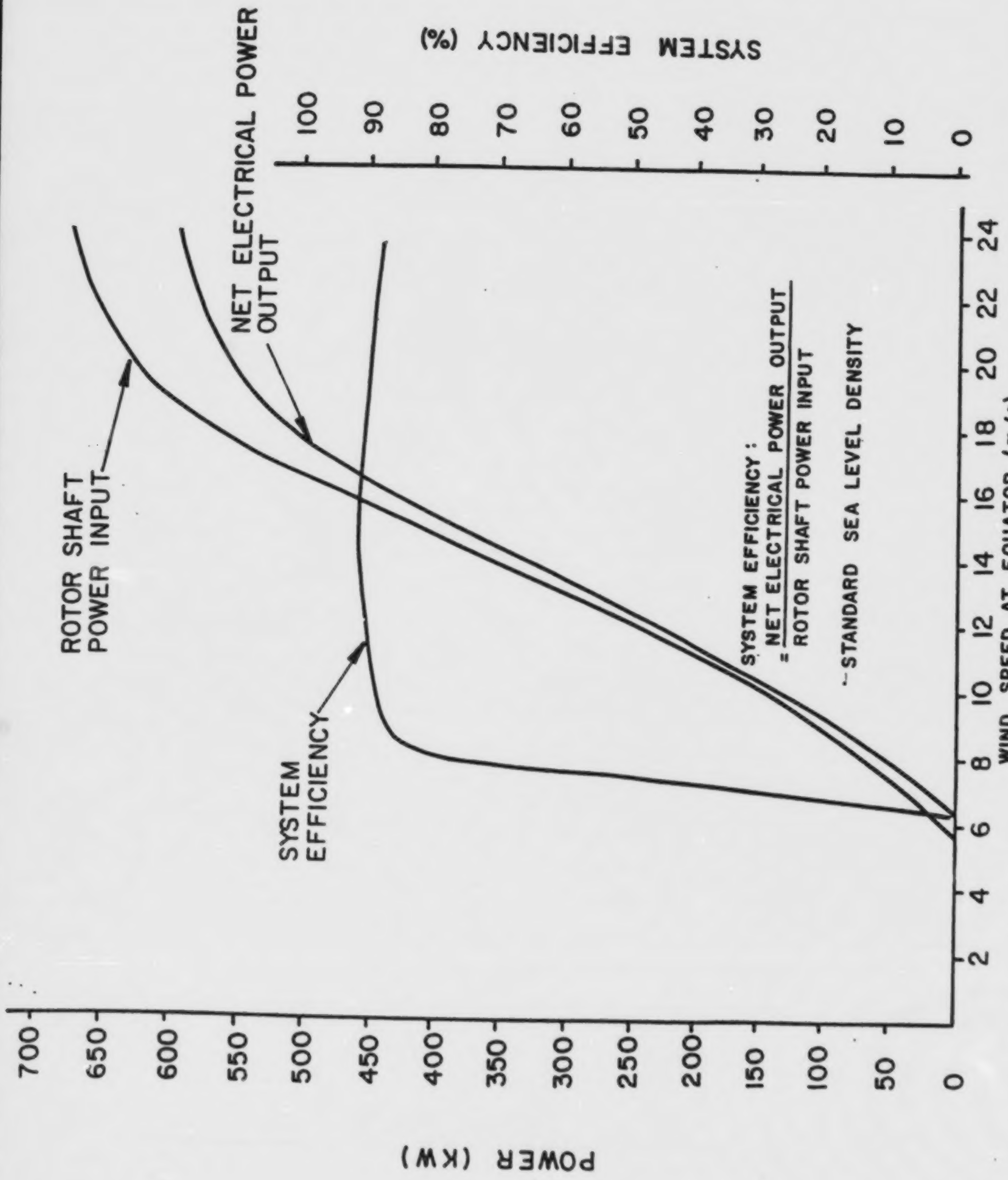


Figure 3 Predicted Performance of the DAF Indal Series 6400 Model 500 kW VAWT

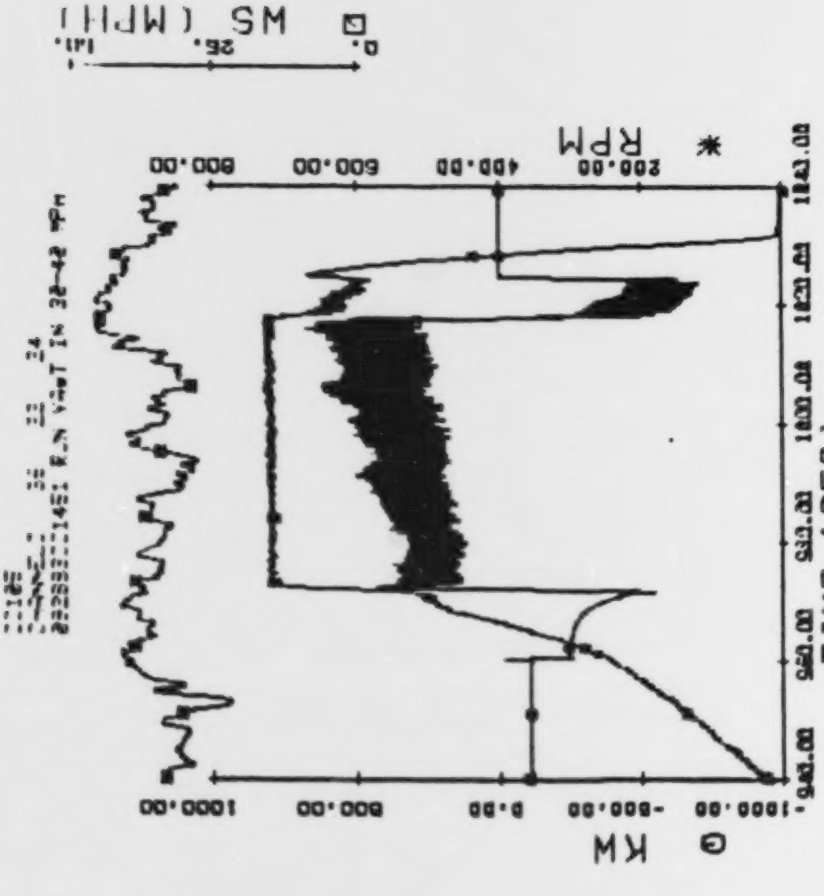


Figure 4 500 kW VAWT Performance Test Data

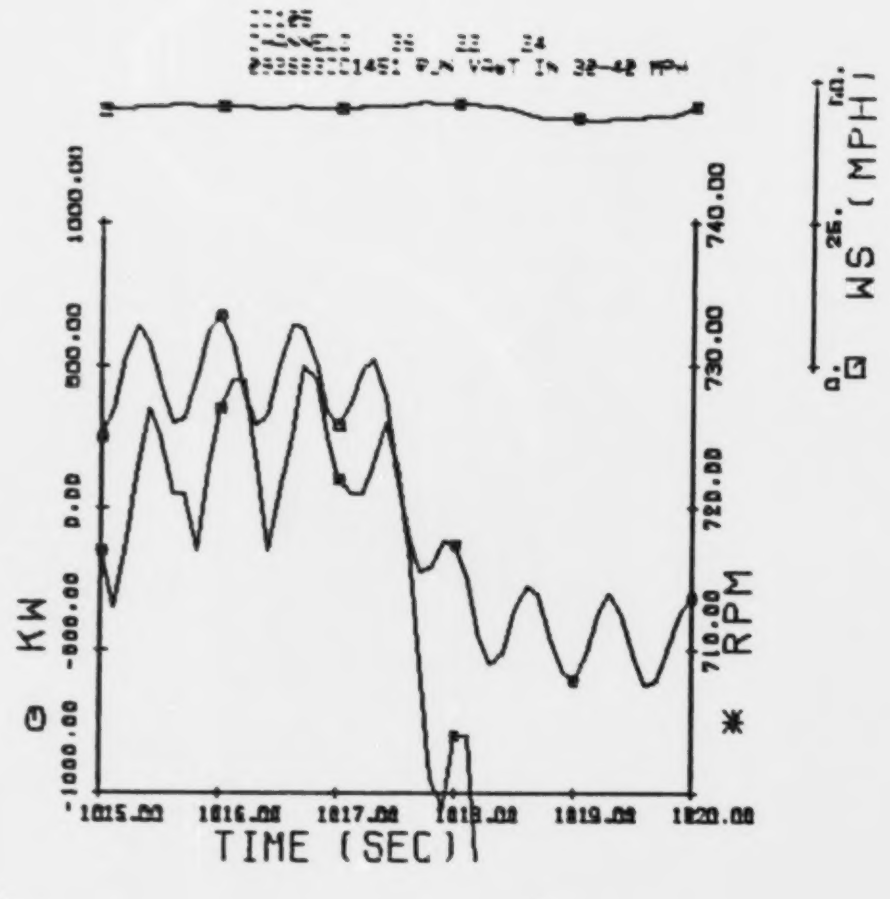


Figure 5 500 kW VAWT Detailed Performance Test Data

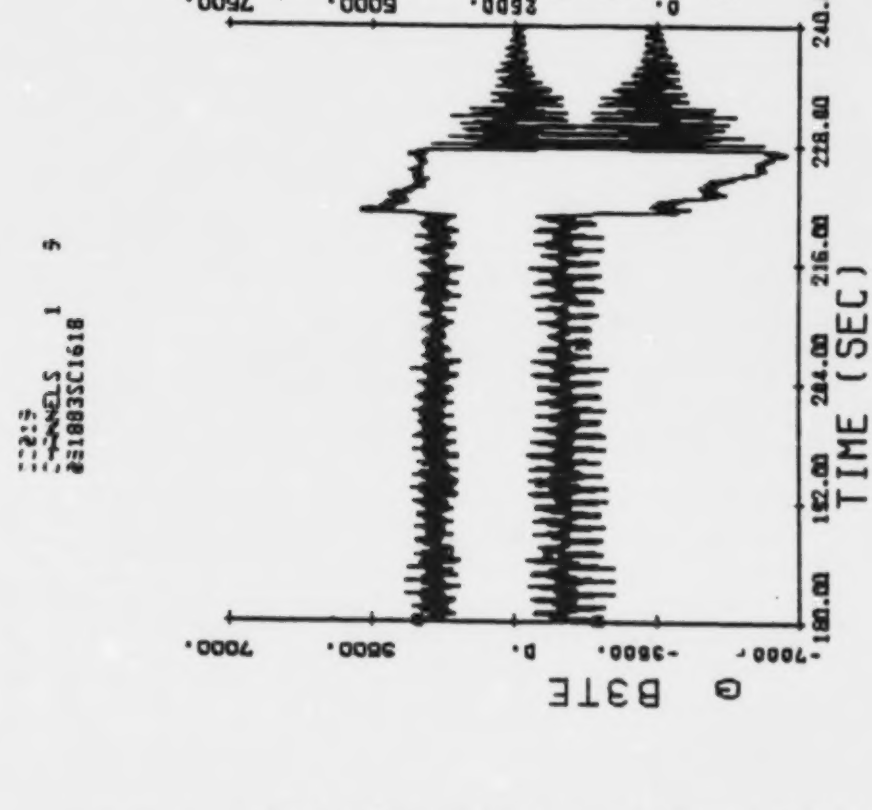


Figure 6 500 kW VAWT Blade Stress Data Before and After Braking

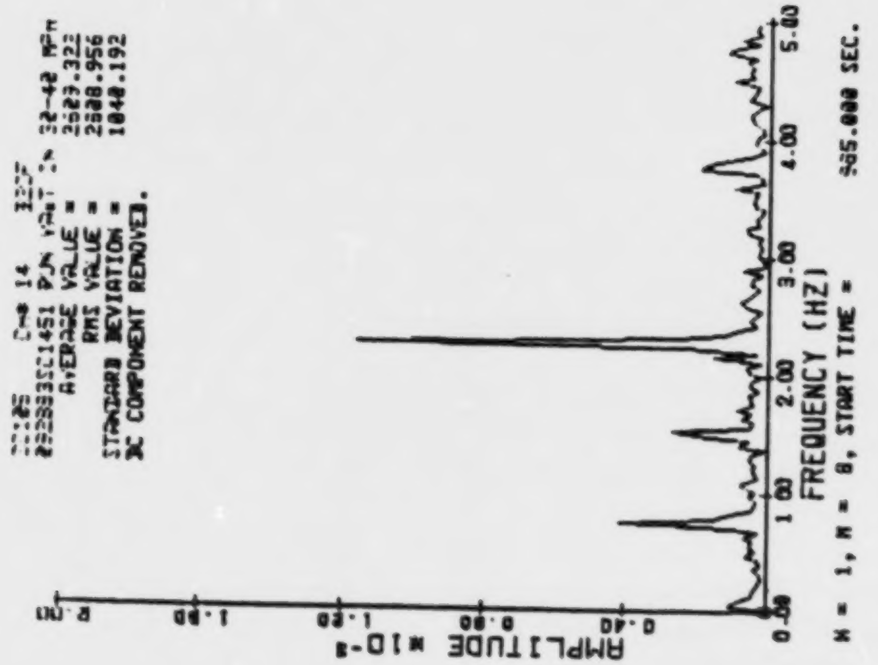


Figure 7 500 kW VAWT Spectral Analysis of Blade Stress Data

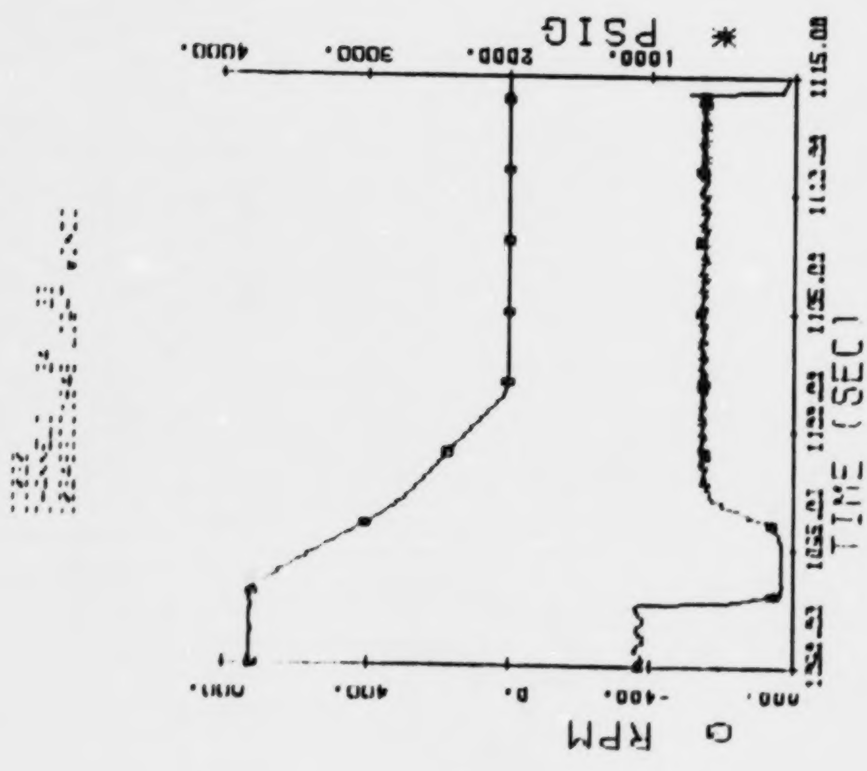


Figure 8 500 kW VAWT Braking Test Data

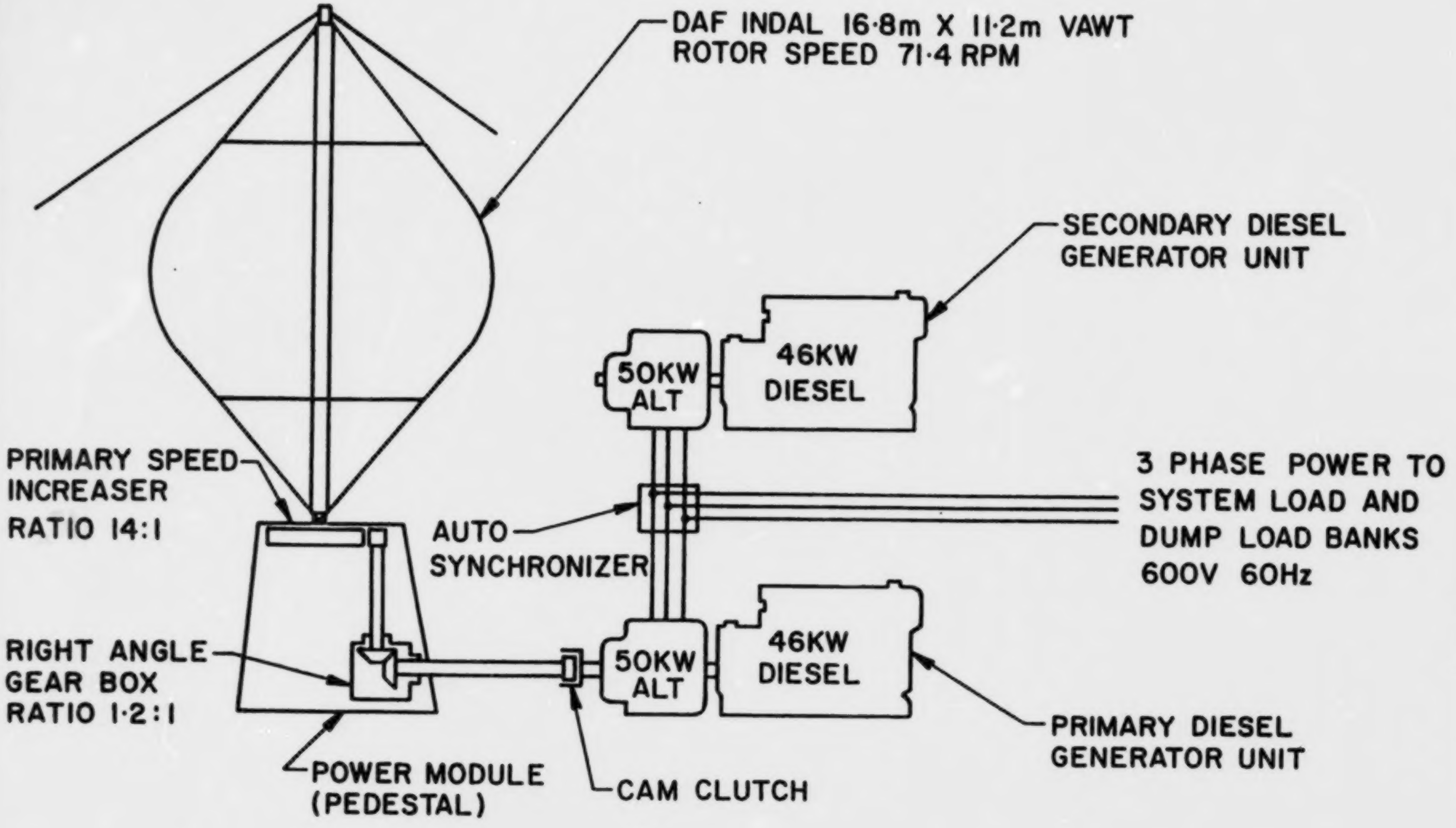

DAF INDAL 16·8m X 11·2m VAWT
ROTOR SPEED 71·4 RPM
SECONDARY DIESEL GENERATOR UNIT
50KW ALT
46KW DIESEL
PRIMARY SPEED INCREASER RATIO 14:1
AUTO SYNCHRONIZER
3 PHASE POWER TO SYSTEM LOAD AND DUMP LOAD BANKS 600V 60Hz
RIGHT ANGLE GEAR BOX RATIO 1·2:1
50KW ALT
46KW DIESEL
PRIMARY DIESEL GENERATOR UNIT
POWER MODULE (PEDESTAL)
CAM CLUTCH

Figure 9 Schematic of Prototype 100 kW Wind Turbine Assisted Diesel Generator System Near Sudbury, Canada

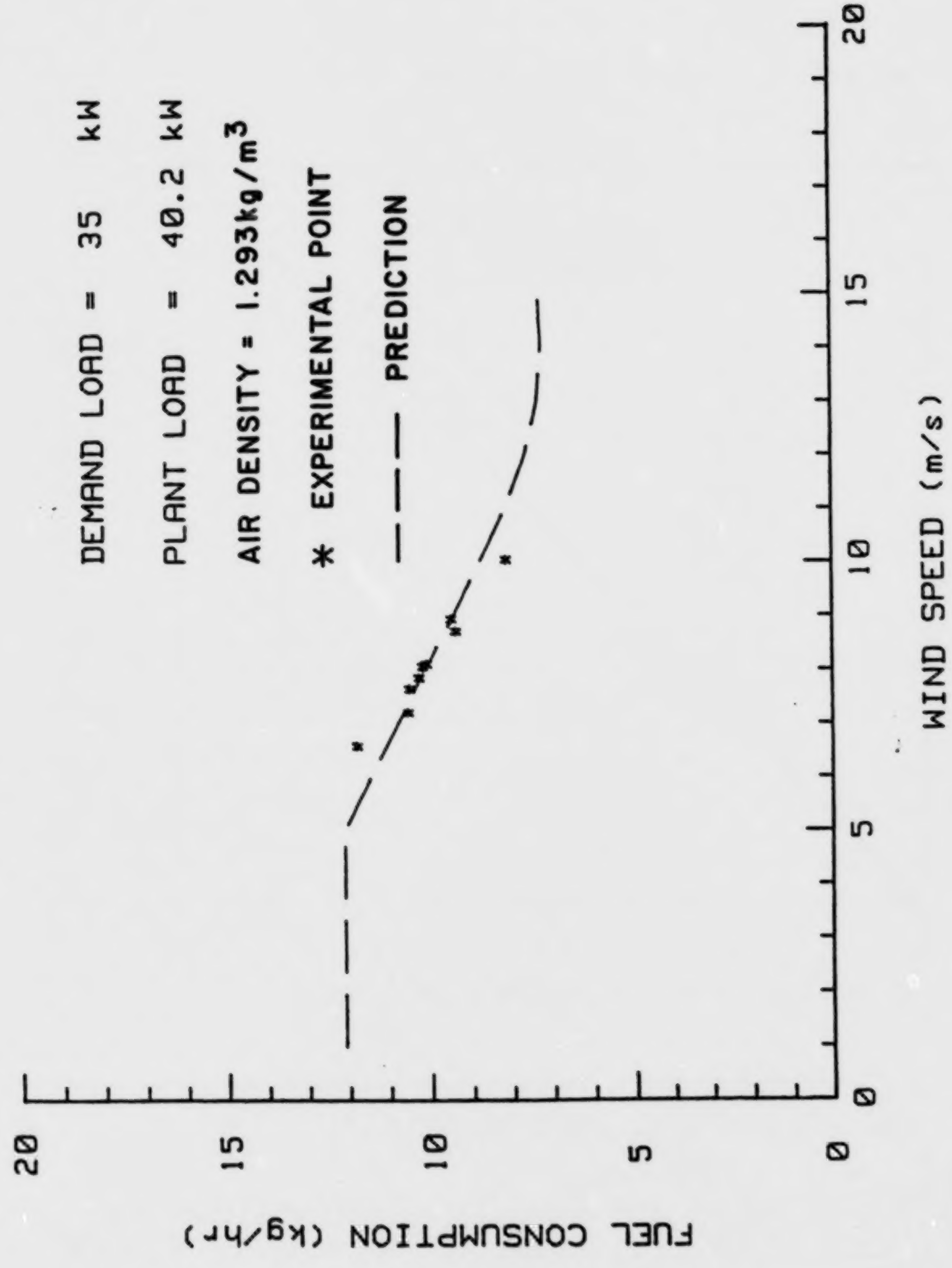
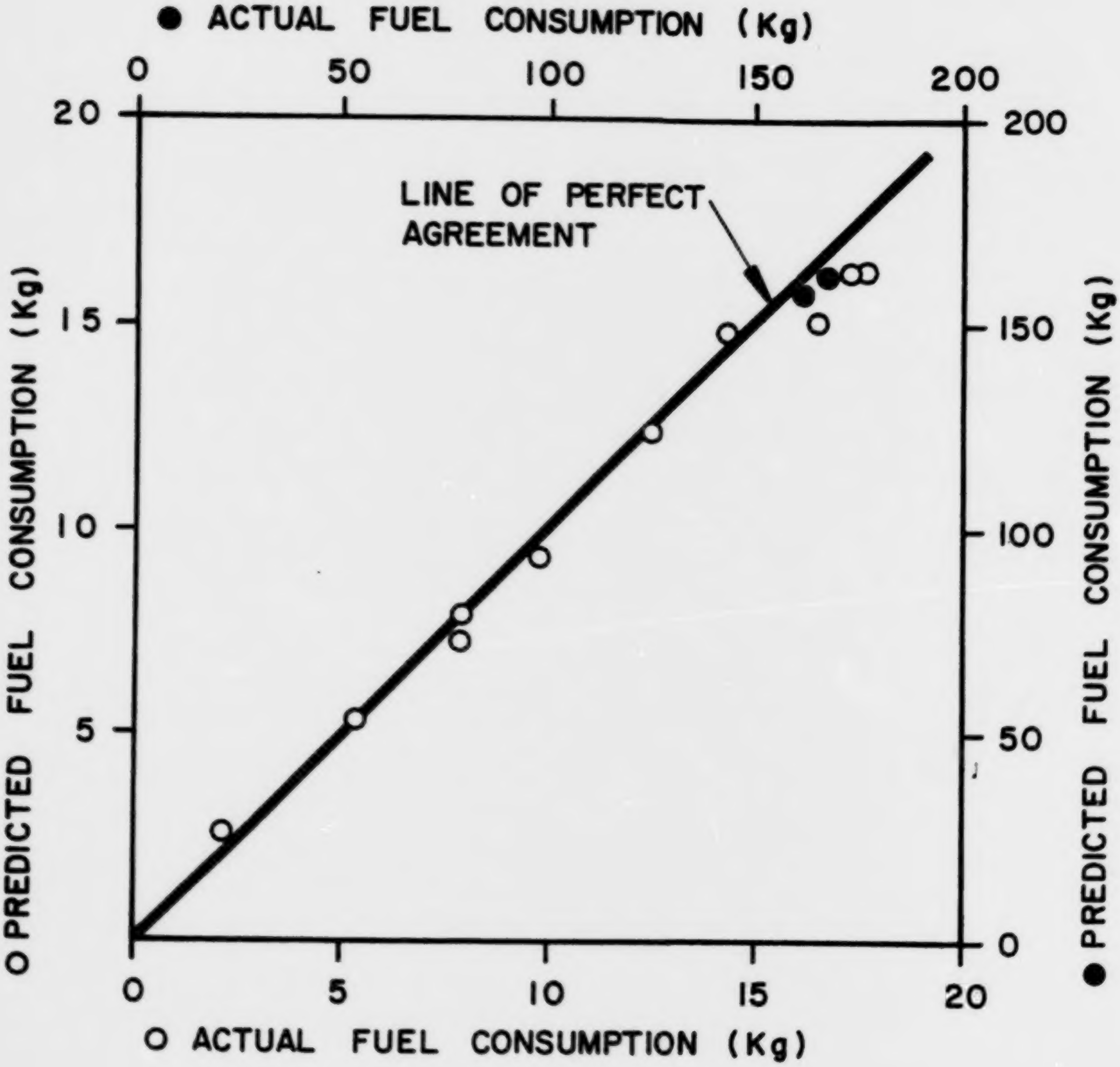


Figure 10 One Minute Average Fuel Consumption Versus Windspeed



POINTS REPRESENT CATEGORY C RESULTS
(ONE DIESEL WITH WIND ASSIST)

Figure 11 Predicted Versus Actual Fuel Consumption - One Diesel in Operation with Wind Turbine Assistance

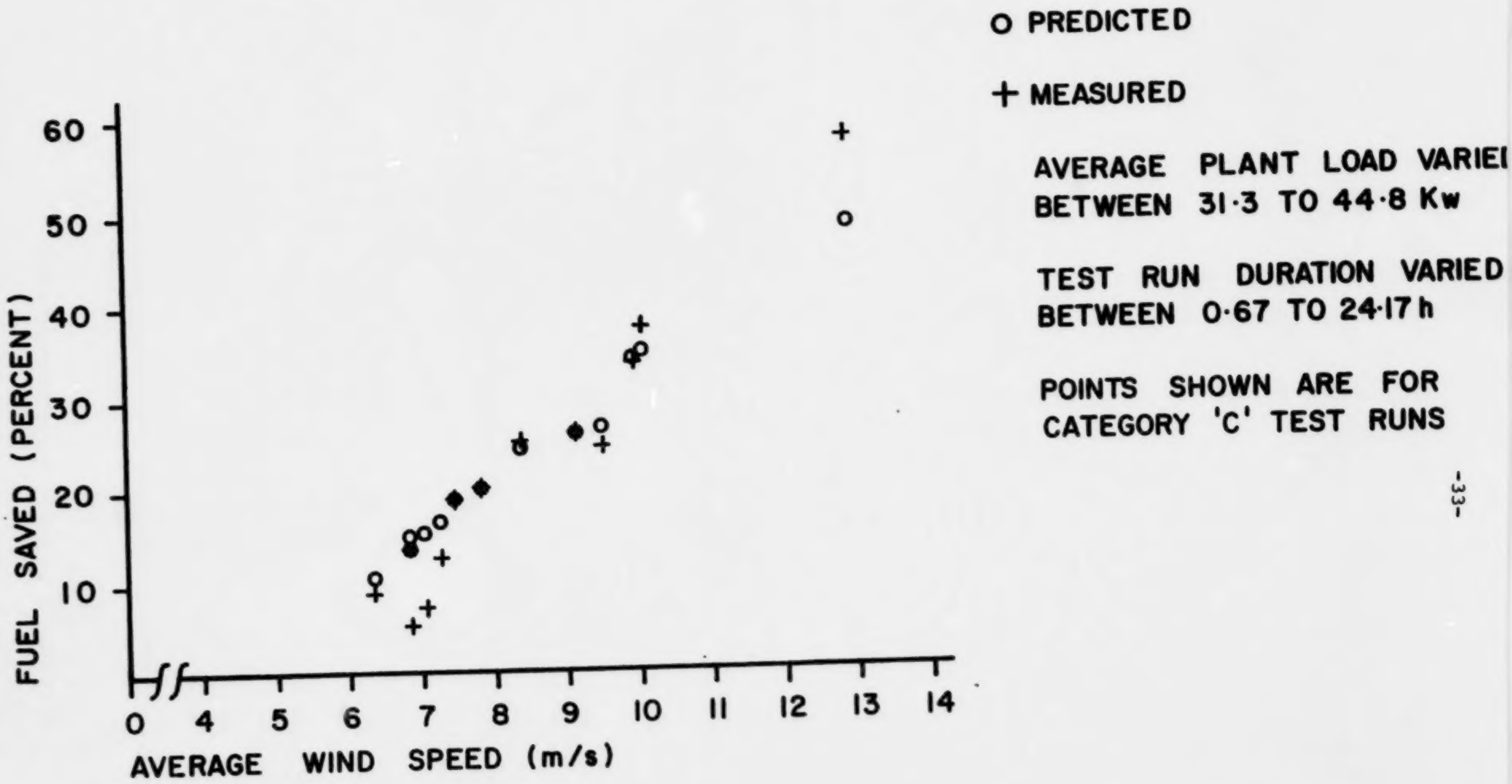


Figure 12 Predicted Versus Measured Fuel Saved - One Diesel in Operation with Wind Turbine Assistance

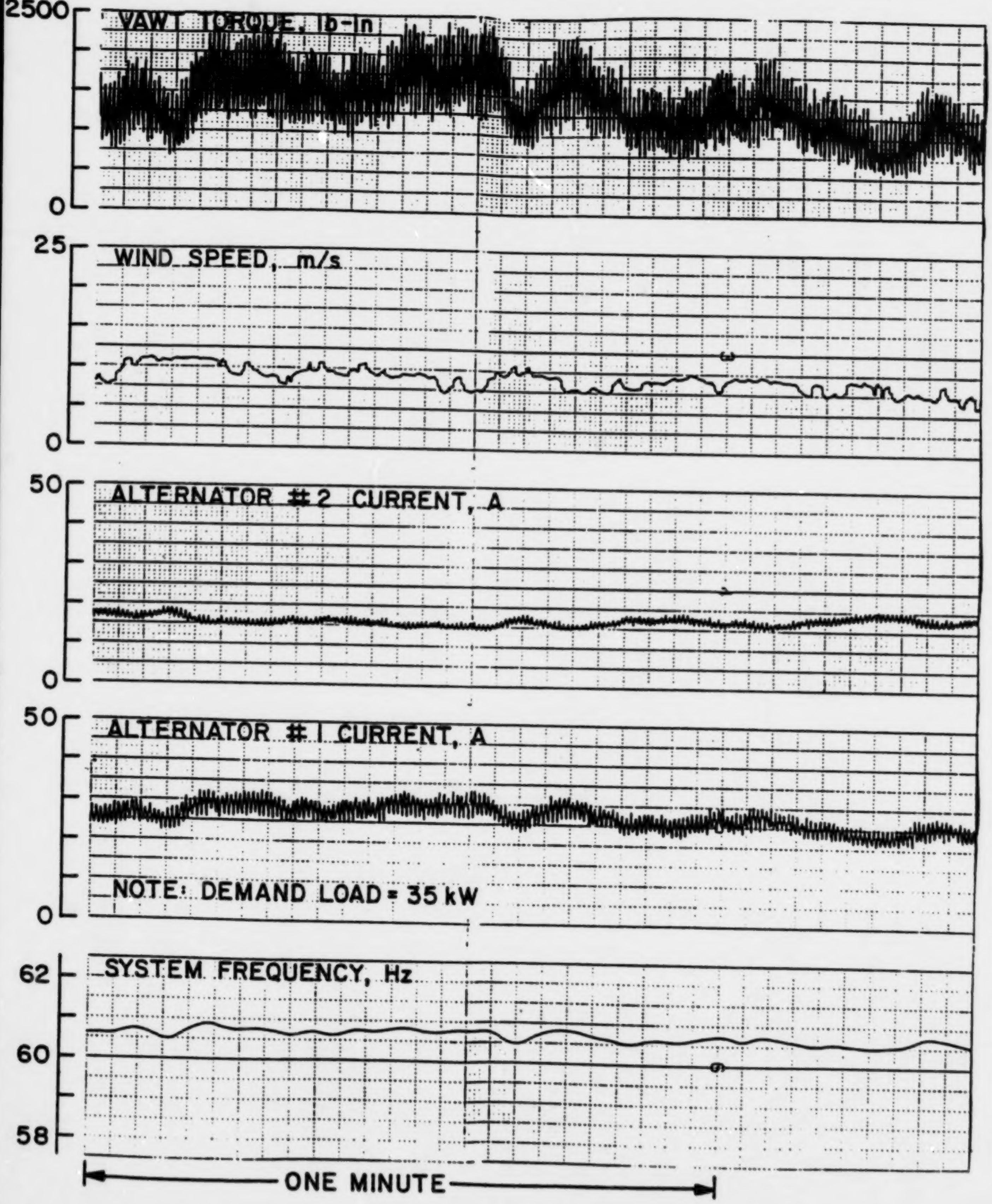


Figure 13 High Speed Chart Records of Two Diesel Operation

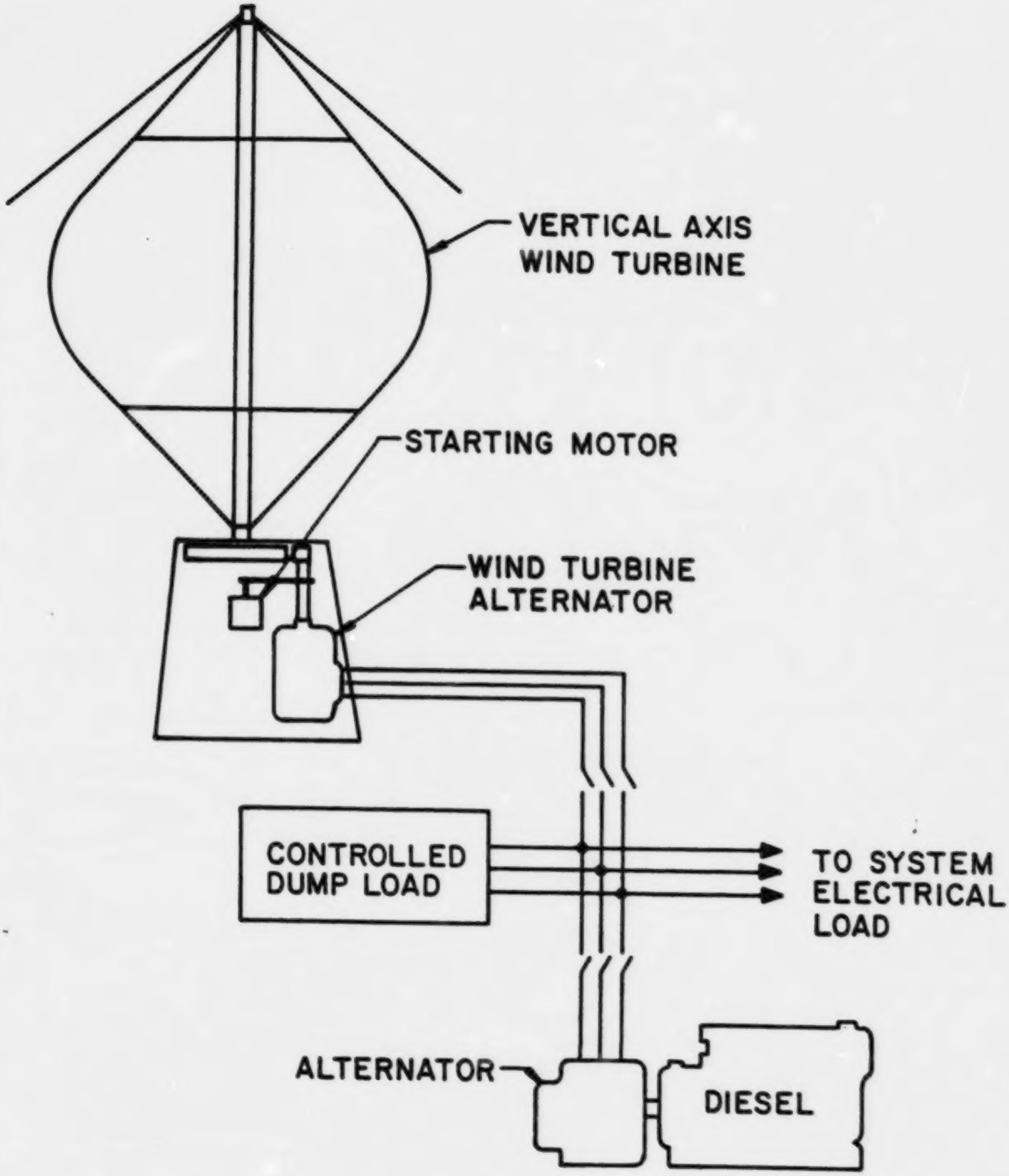

VERTICAL AXIS WIND TURBINE
STARTING MOTOR
WIND TURBINE ALTERNATOR
CONTROLLED DUMP LOAD
TO SYSTEM ELECTRICAL LOAD
ALTERNATOR
DIESEL

Figure 14 Electrically Coupled Stand Alone Wind Diesel

PROJET EOLE - 4 MW VAWTG, CAP-CHAT, QUEBEC

B. Tahmazian and J. Dery
Hydro Quebec

HYDRO-QUÉBEC

INTRODUCTION

The National Research Council Canada (NRC) and the "Institut de Recherche d'Hydro-Quebec (IREQ)" have already installed, at the Magdalen Islands, a 230 kW wind turbine (figure #1). This first success urged them to pursue together their research in the wind energy field and design an even more powerful vertical axis aerogenerator: EOLE.

OBJECTIVE

EOLE is a research and development project. Its objective is to build a 4 MW wind turbine connected to the electrical network and analyze its performance, the aim being to establish a Canadian industrial capability in VAWT generation systems (figure #2). This project, managed by Hydro-Quebec, is based on the premise that the cost of electricity produced by serial model vertical axis generators will be competitive with other means.

COST AND PROGRAM

The cost of the project has been established at 35.2 million current dollars shared equally by NRC and Hydro-Quebec. The aerogenerator will be commissioned in Fall 1985, at which time the machine will undergo a one year evaluation (figure #3).

GENERAL APPROACH

To ensure that the users' needs are considered, the management of the project has been entrusted to Hydro-Quebec, a public utility. Within Hydro-Quebec, the project has been assigned to "direction Equipements de production". This group has experience in the management of both technically complex and financially important projects. This management environment (organization, objectives, standards, procedures, permits, environmental studies, technical choices, etc.) may have excessive constraints on the project, but it ensures a final product which meets the users' needs.

In this view, the reliability, maintainability and availability studies as well as quality control have been incorporated at all phases of the project: the equipment is specified according to approved standards and its availability on the market and chosen on a competitive basis. The training of the operators is part of the project.

To meet the standards of a power station, EOLE must be cost competitive and produce power of conventional quality, operating in a reliable and secure way with minimum maintenance and inspection. The energy cost should be acceptable for a given geographical location and its operation must not require special skills, aptitudes and knowledge above average qualifications for similar tasks.

However, to meet the objectives of the project, the aerogenerator will be over-instrumented which will not necessarily be the case in a serial model.

ORGANIZATION

The project organization chart is shown in figure #4. The responsibility of the project manager consists of harmonizing the work assigned to consulting engineers and manufacturers (practical part) with the findings of researchers (theoretical part) using standards and procedures of Hydro-Quebec (user's part).

SITE SELECTION

For site selection and for obtaining governmental permit, thorough technical and environmental studies were carried out such as: atmospheric conditions, electromagnetic interferences, network connections, foundations, acoustic noise, archaeological potential, habitat, collision of migrating birds, tourism, agriculture, visual aspect, transportation and telecommunication infrastructure, etc.

Local public consultation has corroborated the choice for the site at Cap-Chat, a coastal village of the Gaspe Peninsula (figure #5). The site is approximately at an elevation of 100 m. The climate is maritime with an annual average wind speed at equator height of the rotor of about 9 m/s and the region is known for its ice accumulation during the winter season.

GENERAL DESCRIPTION

Site layout

An exclusion area of about 100,000 square meters bordered by a fence containing the guy wire anchors limits the access to the wind turbine and the three prefabricated modules containing the electrical apparatus and the control system. The layout is completed by a road network, parking, and conventional systems such as sanitary, lighting, etc. (figure #6).

The aerogenerator

The aerogenerator is 110 meters high and is maintained vertically with six guy wires as shown in figure #7. It is mounted on a concrete base and drives a generator which produces 4 MW at 14.25 RPM at winds of 20.7 m/s.

The generator is a low frequency sysnchronous AC type directly coupled with the rotor. It is connected to the network by means of a static frequency converter and a step-up transformer (figure #8).

The static frequency converter gives the opportunity to operate the aerogenerator in a variable speed mode.

The drive train which couples the rotor to the generator includes essentially a pivot, a support bearing, a mechanical brake and a flexible coupling.

AEROGENERATOR CONTROL

Aerogenerator control is carried out electrically through the static frequency converter. It includes starting, generating and electrical braking at selected or variable speeds.

Modular design

Aerogenerators will be normally installed in remote areas probably with expensive means of transportation; EOLE is designed to minimize site work. All sub-systems are preassembled and tested in plant; the site work consists mainly to assemble sub-systems. Once the generator is installed, the maintenance should be done with standard equipment.

Security

Public and personnel security is the first priority, equipment protection coming second.

Public and personnel security in general is accomplished by controlling the access to the site.

Equipment is protected by control systems which assure its survival. The rotor is self-protected against over-speed by an independent aerobrake system. The generator has a conventional protection system by means of it breakers. The six guy wire tie-down system permits the total loss of one without endangering the aerogenerator.

TECHNICAL PRELIMINARY CHOICES

The base configuration is the result of technical choices made through close collaboration with NRC and IREQ.

During 1978 to 1980, technical studies were performed to evaluate the power production performance of large wind turbines. One of these studies, done by consulting engineers in collaboration with a manufacturer, has compared vertical with horizontal axis aerogenerators. Among the conclusions of these studies, we find the following:

- The VAWTG has the advantage of a basically simple design. In particular, the ground level location of the power train places minimal constraints on configuration and physical size of the equipment rating. This widens the scope for increased energy production, reduces the cost of energy and provides a major advantage in terms of reliability, operation and maintenance.

- The VAWTG is fully competitive with the HAWTG within the accuracy of the analysis. In fact, the specific data indicates technical and economic superiority for the VAWTG.

Following these studies, a preliminary technical definition has been elaborated in 1981 recommending the development of a VAWTG with general characteristics as shown in figures # 9 and #10.

TECHNICAL CHOICES DURING ENGINEERING

Figure #11 shows the up-dated principal technical characteristics of the project.

Aerobrakes

Emergency aerobrakes were added to the rotor as a last means of protection in the event of loss of generator control.

Material selection

Aluminum, composite materials and steel were considered for the rotor; steel was selected for the column and the blades. The choice has been made on an ecoonomical basis for the prototype.

Power train

The power train includes all rotating equipment connected to the rotor including the generator. A comparison study between direct drive and gear box was done. The direct drive option was retained based on it technical superiority due to its simplicity, efficiency and reliability.

Variable speed

A constant speed link of the aerogenerator to the network was compared with an asynchronous link. The asynchronous link was retained because of its superiority. It permits variable speed operation which is essential to increase our knowledge and has a potential to capture more energy. The asynchronous link includes an inverter which converts the energy produced by the generator to the network frequency.

Guy wires

The two governing factors for selecting the number of guy wires were the stability of the top bearing and the facility of replacing one guy wire without endangering the aerogenerator. The option of six guy wires was retained.

CONCLUSION

The presented configuration is the result of different technological choices decided up to this date. Engineering is progressing and further optimization may result in modification of the base configuration.

Due to our methodical approach proven on other major projects and the support of highly specialized resources coming from different groups such as scientific research agencies, consulting engineers, industry and public utilities, Project EOLE is advancing in accordance with our schedule, financial and technical expectations.

To date, results are very promising and reinforce our belief in the future of wind energy and more specifically in vertical axis aerogenerators.

QUESTIONS:

Q. What is the total cost of the entire project from concept to prototype erection?

A. The total cost of the design and construction of the project is $35.2 million. We are now at the stage of going for bids for the two major components. This is very important information. It will give us a lot of precision on the final cost.

Q. How do you plan to fabricate the steel blades?

A. The steel blades for the rotor have gone out for bids. It will be conventional steel fabrication technology as used in turbines for nuclear or conventional stations, materials that can do this kind of job. It is well known technology.

Q. What do you estimate the total system weight will be?

A. The rotor is about 350 tons and the generator about 180 tons.

Q. When is your anticipated erection date for the first prototype?

A. Construction will occur over a 4 month season in 1984, particularly the roads, site preparation and fences. We will return in spring 1985 to erect and commission by fall 1985.

Q. If everything works out, what does Hydro Quebec plan to do with this type of thing?

A. There may be a small windfarm of 500 kW Darrieus turbines installed at the Magdalen islands. There may be other projects in which EOLE may be used in the same size but at a higher power rating.

Q. There is always the question of size versus making more of the smaller units. Have you investigated how large these units will get before they reach an ultimate size?

A. Our consulting engineers did some studies in 1980. It seems they can go to 6, 8 or 10 MW and be cost competitive.

Q. What is the advantage of having one of those as opposed to 8 DAF 500 kW turbines?

A. Cost competitive, that is what I believe.

Q. What is your cost per installed kW?

A. I don't have the details here now but I know that later today there will be speakers talking about the cost per kW comparison. We have the figures but I don't have them with me now.

Q. You might anticipate some changes from how you now see it, could you elaborate on that?

A. Yes, when we went for bids we had a base configuration that we really believe will work at this time, but there may be alternatives that the bidder can propose. One of them may be cost competitive and technically very interesting. These are the changes that could happen in optimizing to a better solution. We are searching for cheaper and technically better solutions, if manufacturers can propose something to us.

Q. I'm extremely interested in the braking system. Some of your figures show a dual or triple type of braking system, airbrake, low and high speed. Could you elaborate on the purpose of these?

A. Having removed the gearbox there is no requirment for a high speed brake. The system is designed to be able to keep the machine under control all the time. The static frequency converter will permit us to brake the machine by putting more power into the grid than the generator/rotor usually does. In addition, we also have a resistor bank so we can use electrical braking if we can't use the grid. Now we use mechanical braking for stopping the machine and as a back-up also. The logic of having air brakes on the rotor, is a matter of principle. the rotor is an expensive piece of equipment and we want it to protect itself from any fault. That is the philosophy. Normally we will run always on electrical control. The mechanical brake is used only for stopping and as little as possible. The air brake is used only for emergency when everything else has failed.

Q. There seems to be a lot of horizontal axis development in the states and vertical axis development in Canada. Could you go over in detail the advantages you found in vertical axis.

A. Some of our consulting engineer studies compared horizontal axis with vertical axis. Results of the studies are that at the same stage of technological advance, vertical axis is more simple and reliable and can be more cost competitive. This is what the systematic and methodical approach gave us as a result. I have visited some large horizontal axis machines and I also believe that they need more control systems for yawing, feathering and teetering. Complex systems are subject to error and complication. This is the challenge. We have to prove that vertical axis turbines are more competitive because they are simpler.

Q. What is Hydro-Quebec's total contribution?

A. One half, so $17.6 million.

Q. What would be the production cost for one of these machines?

A. We project $3 - 5 million manufacturing cost for production models and other costs added to that. This is the other challenge.

Q. Is it the objective of Hydro-Quebec to participate in selling them?

A. I don't think it is presently included in Hydro-Quebec's system planning to use it in its normal electricity production. It is still at the stage of research and development. Hydro-Quebec may not itself build these kinds of machines; it may go to a kind of consortium and take royalties. We are more interested in the research and enhancing this kind of energy producing technology to have future options for energy production. I would like to stress again that it is a research project for us. We have a research centre (IREQ) which is well directed in this field and Hydro-Quebec is just providing a facility to them with this project.

Q. Will there be a static frequency converter on the serial models?

A. This is under discussion. It is not only for the prototype. We think it is not a very expensive item, we think presently it should be included in the production models.

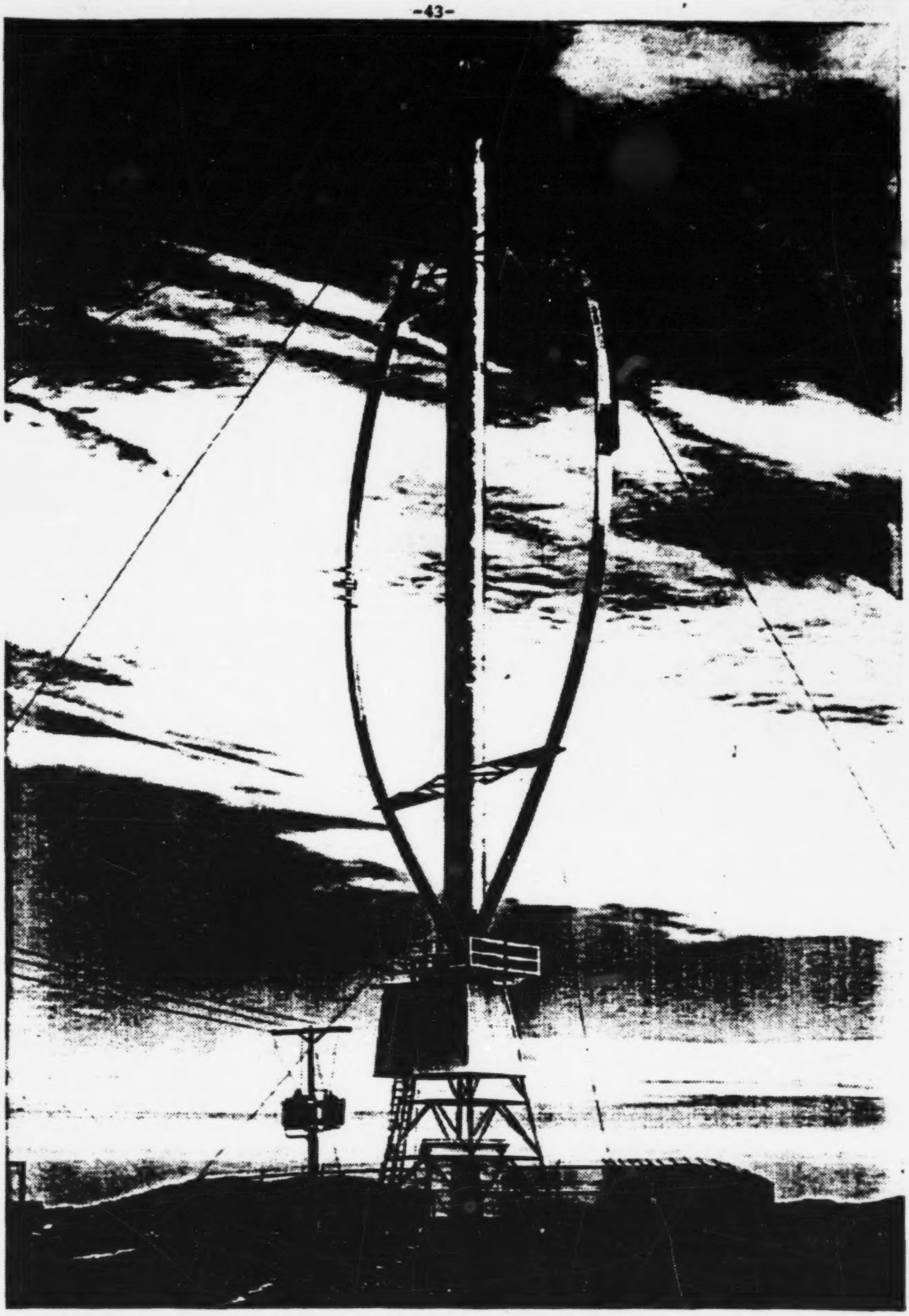


FIGURE 1 - VERTICAL AXIS WIND TURBINE - MAGDALEN ISLAND 230 KW

FIGURE 2

The major objectives of Projet EOLE are:

To confirm the technical feasibility of megawatt-scale VAWT generator systems;

To evaluate the design and to determine the operating, performance, and control characteristics of megawatt-scale VAWT generator systems, and their interactions with the recipient electrical network;

To verify analytical techniques used for prediction of the technical performance and to indicate economic potential of VAWT generator systems;

To generate knowledge and experience of value to Canadian users and manufacturers of VAWT generator systems;

To encourage and enhance the development of Canadian industrial capability in VAWT generator systems and components;

To obtain operational experience with a megawatt-scale VAWT generator system;

To examine the environmental aspects of megawatt-scale VAWT generator system.

ANNUAL COST DISTRIBUTION
(in million current dollars)

Total	1981	1982	1983	1984	1985	1986
35.2	0.5	2.9	6.0	12.0	12.0	1.8

CALENDAR

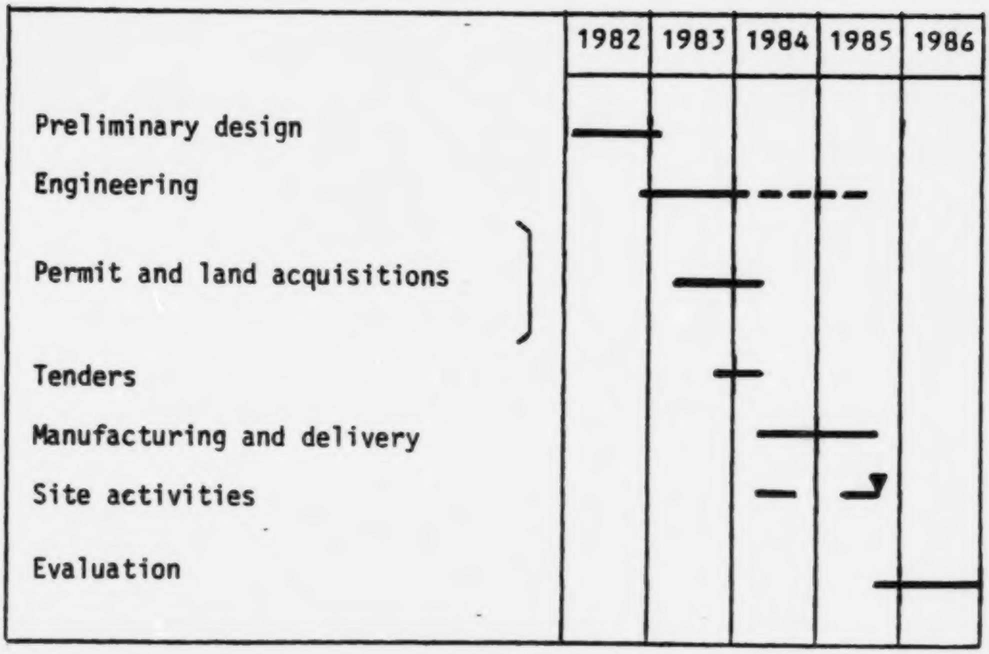
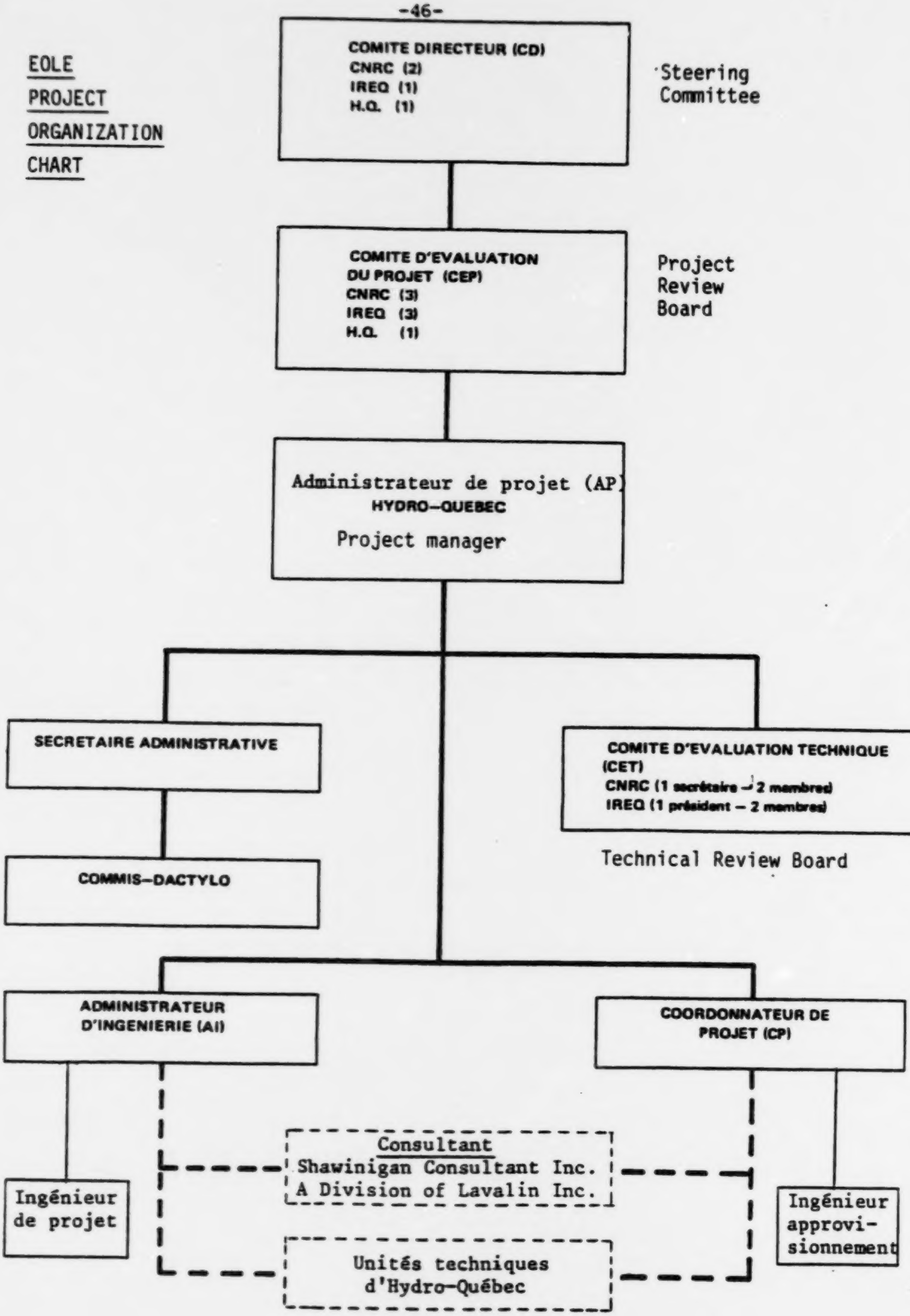


FIGURE 3

EOLE
PROJECT
ORGANIZATION
CHART


COMITE DIRECTEUR (CD)
CNRC (2)
IREQ (1)
H.Q. (1)
Steering Committee
COMITE D'EVALUATION DU PROJET (CEP)
CNRC (3)
IREQ (3)
H.Q. (1)
Project Review Board
Administrateur de projet (AP)
HYDRO-QUEBEC
Project manager
SECRETAIRE ADMINISTRATIVE
COMMIS-DACTYLO
COMITE D'EVALUATION TECHNIQUE (CET)
CNRC (1 secrétaire – 2 membres)
IREQ (1 président – 2 membres)
Technical Review Board
ADMINISTRATEUR D'INGENIERIE (AI)
COORDONNATEUR DE PROJET (CP)
Consultant
Shawinigan Consultant Inc.
A Division of Lavalin Inc.
Unités techniques d'Hydro-Québec
Ingénieur de projet
Ingénieur approvisionnement

ORGANIGRAMME DE PROJET EOLE

FIGURE 4

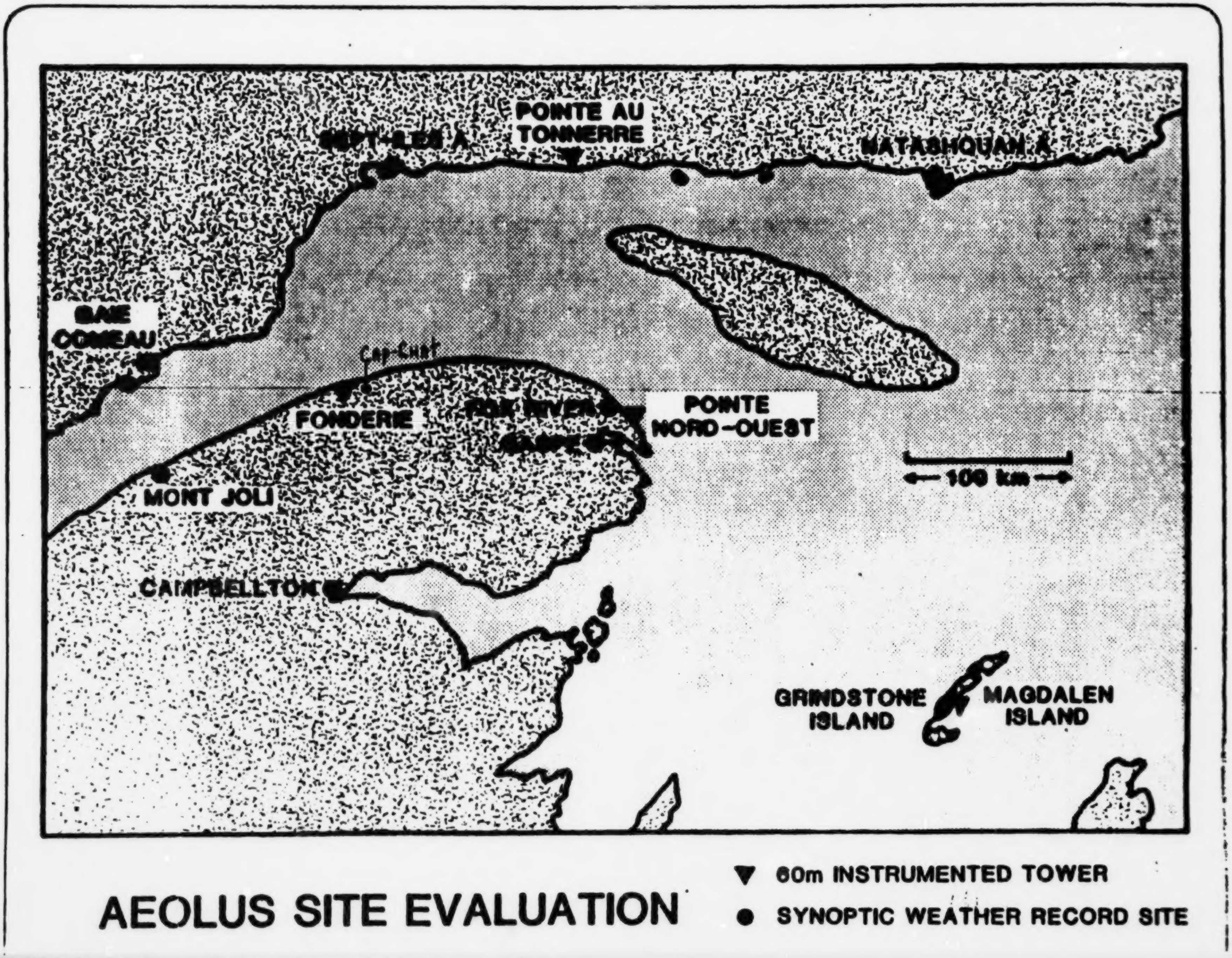
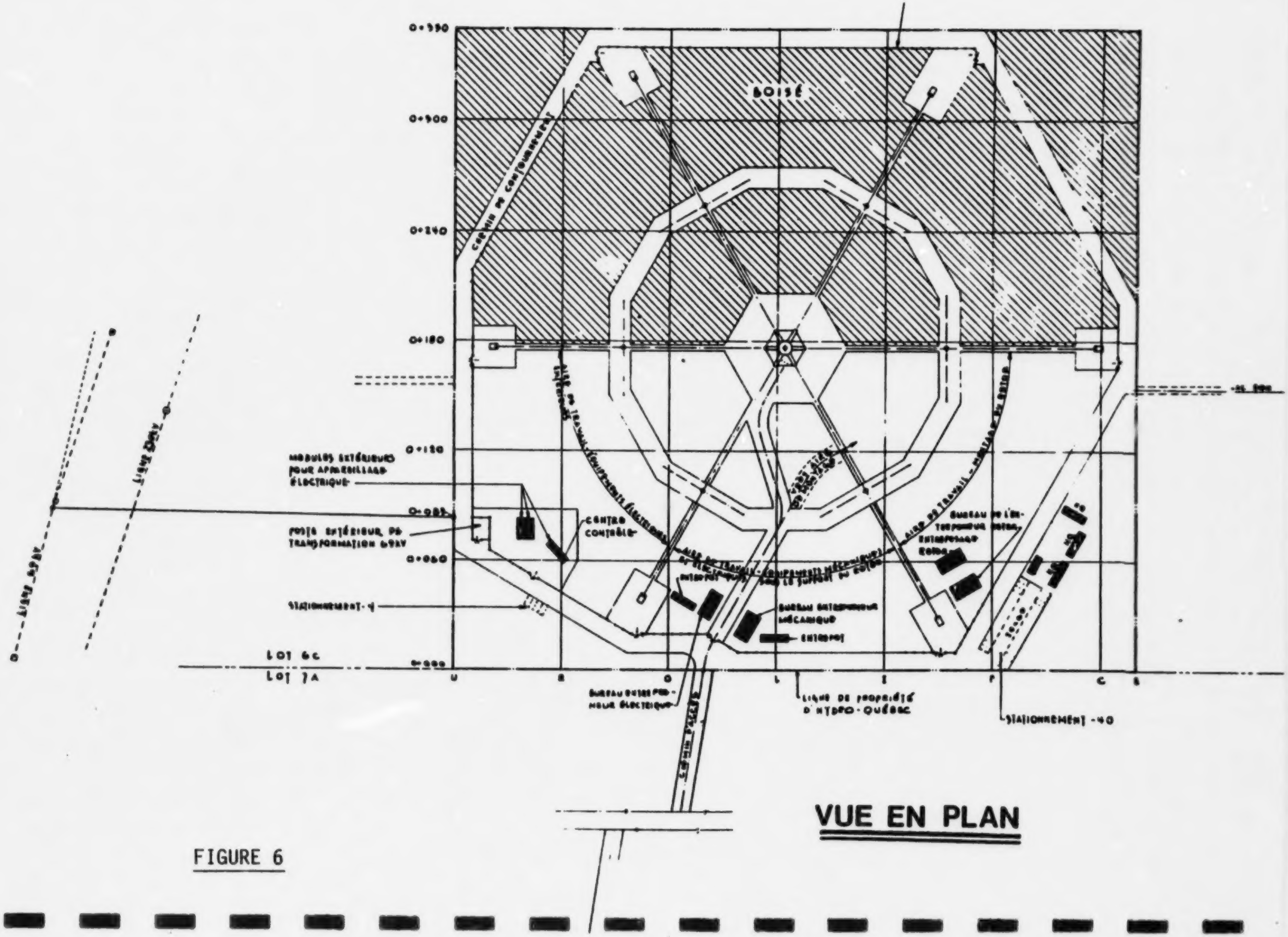

SEPT-ILES A
POINTE AU TONNERRE
NATASHQUAN A
BAIE COMEAU
Cap-Chat
FONDERIE
FOX RIVER
GASPE
POINTE NORD-OUEST
MONT JOLI
100 km
CAMPBELLTON
GRINDSTONE ISLAND
MAGDALEN ISLAND
AEOLUS SITE EVALUATION
▼ 60m INSTRUMENTED TOWER
● SYNOPTIC WEATHER RECORD SITE

FIGURE 5


BOISÉ
CHEMIN DE CONTOURNEMENT
0+330
0+300
0+240
0+180
0+120
0+083
0+060
0+000
U
B
O
L
I
F
G
E
MODULES EXTÉRIEURS POUR APPAREILLAGE ÉLECTRIQUE
POSTE EXTÉRIEUR DE TRANSFORMATION 69KV
CENTRE CONTRÔLE
STATIONNEMENT-4
LOT 6C
LOT 7A
BUREAU ENTREPRENEUR ÉLECTRIQUE
CHEMIN D'ACCÈS
LIGNE DE PROPRIÉTÉ D'HYDRO-QUÉBEC
STATIONNEMENT -40
BUREAU ENTREPRENEUR MÉCANIQUE
ENTREPÔT
BUREAU DE L'ENTREPRENEUR GÉNÉRAL
ENTREPOSAGE
AIRE DE TRAVAIL - ÉQUIPEMENTS ÉLECTRIQUES
AIRE DE TRAVAIL - ÉQUIPEMENTS MÉCANIQUES
AIRE DE TRAVAIL - MONTAGE DU SUPPORT DU ROTOR
LIGNE 69KV

VUE EN PLAN

FIGURE 6

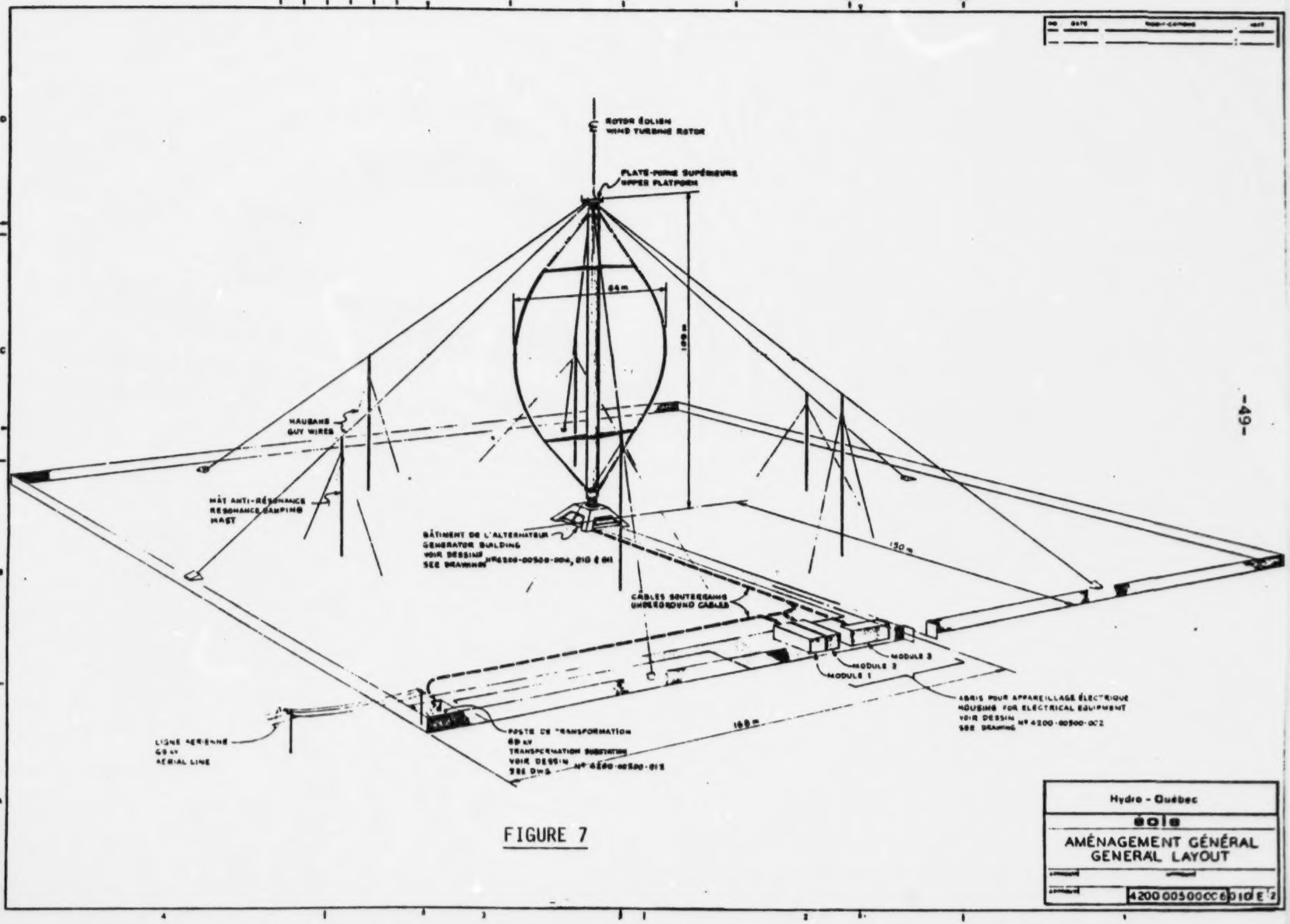

ROTOR ÉOLIEN
WIND TURBINE ROTOR
PLATE-FORME SUPÉRIEURE
UPPER PLATFORM
64 m
109 m
HAUBANS
GUY WIRES
MÂT ANTI-RÉSONANCE
RESONANCE DAMPING MAST
BÂTIMENT DE L'ALTERNATEUR
GENERATOR BUILDING
VOIR DESSIN
SEE DRAWING Nº 4200-00500-004, 010 & 011
150 m
CÂBLES SOUTERRAINS
UNDERGROUND CABLES
MODULE 1
MODULE 2
MODULE 3
ABRIS POUR APPAREILLAGE ÉLECTRIQUE
HOUSING FOR ELECTRICAL EQUIPMENT
VOIR DESSIN
SEE DRAWING Nº 4200-00500-002
LIGNE AÉRIENNE
69 kV
AERIAL LINE
POSTE DE TRANSFORMATION
69 kV
TRANSFORMATION SUBSTATION
VOIR DESSIN
SEE DWG Nº 4200-00500-012
169 m
Hydro - Québec
eole
AMÉNAGEMENT GÉNÉRAL
GENERAL LAYOUT
4200 00500 0006 010 E 2

FIGURE 7

ÉOLE

PRINCIPAUX COMPOSANTS

MAJOR COMPONENTS

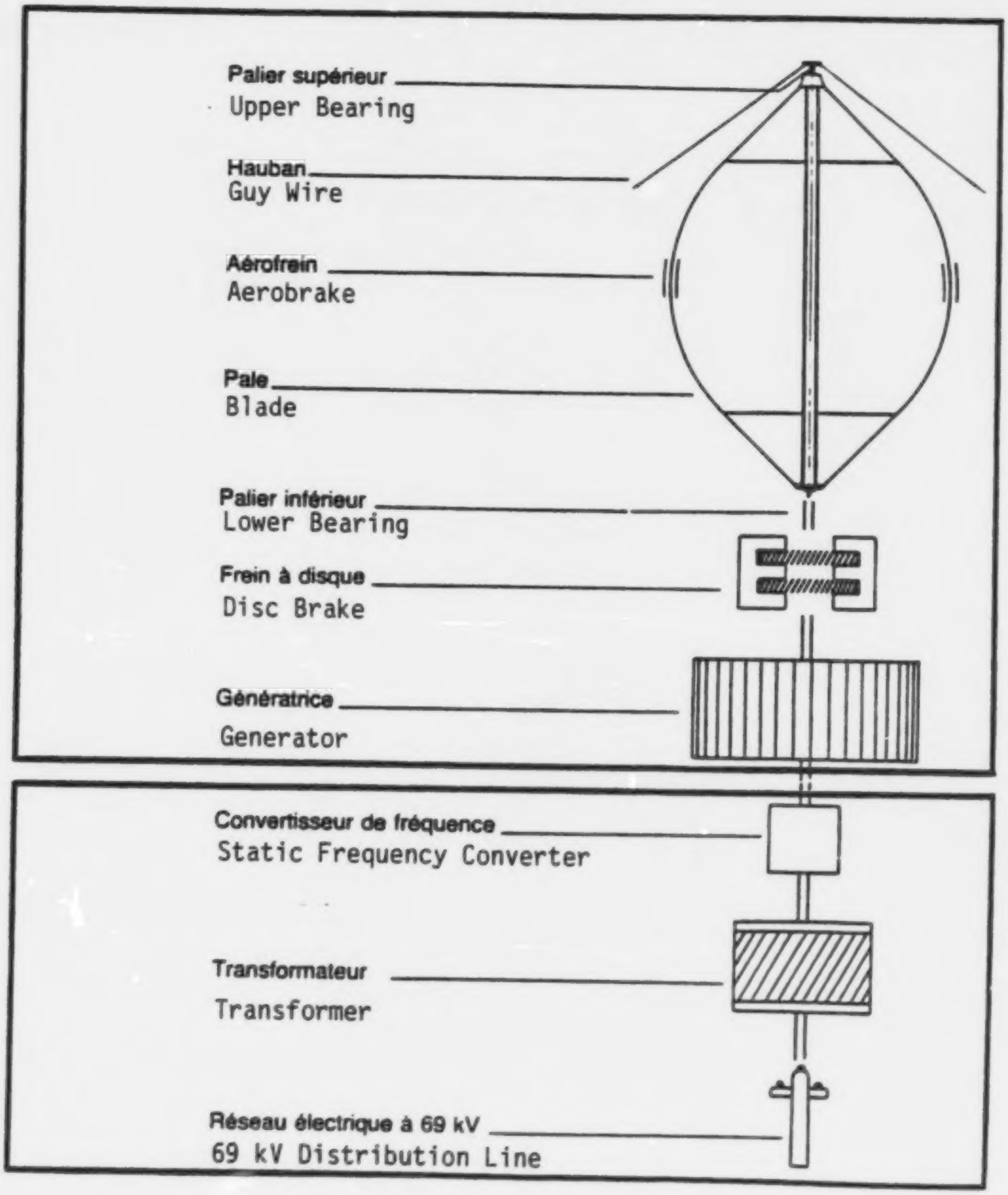

Palier supérieur
Upper Bearing
Hauban
Guy Wire
Aérofrein
Aerobrake
Pale
Blade
Palier inférieur
Lower Bearing
Frein à disque
Disc Brake
Génératrice
Generator
Convertisseur de fréquence
Static Frequency Converter
Transformateur
Transformer
Réseau électrique à 69 kV
69 kV Distribution Line

FIGURE 8

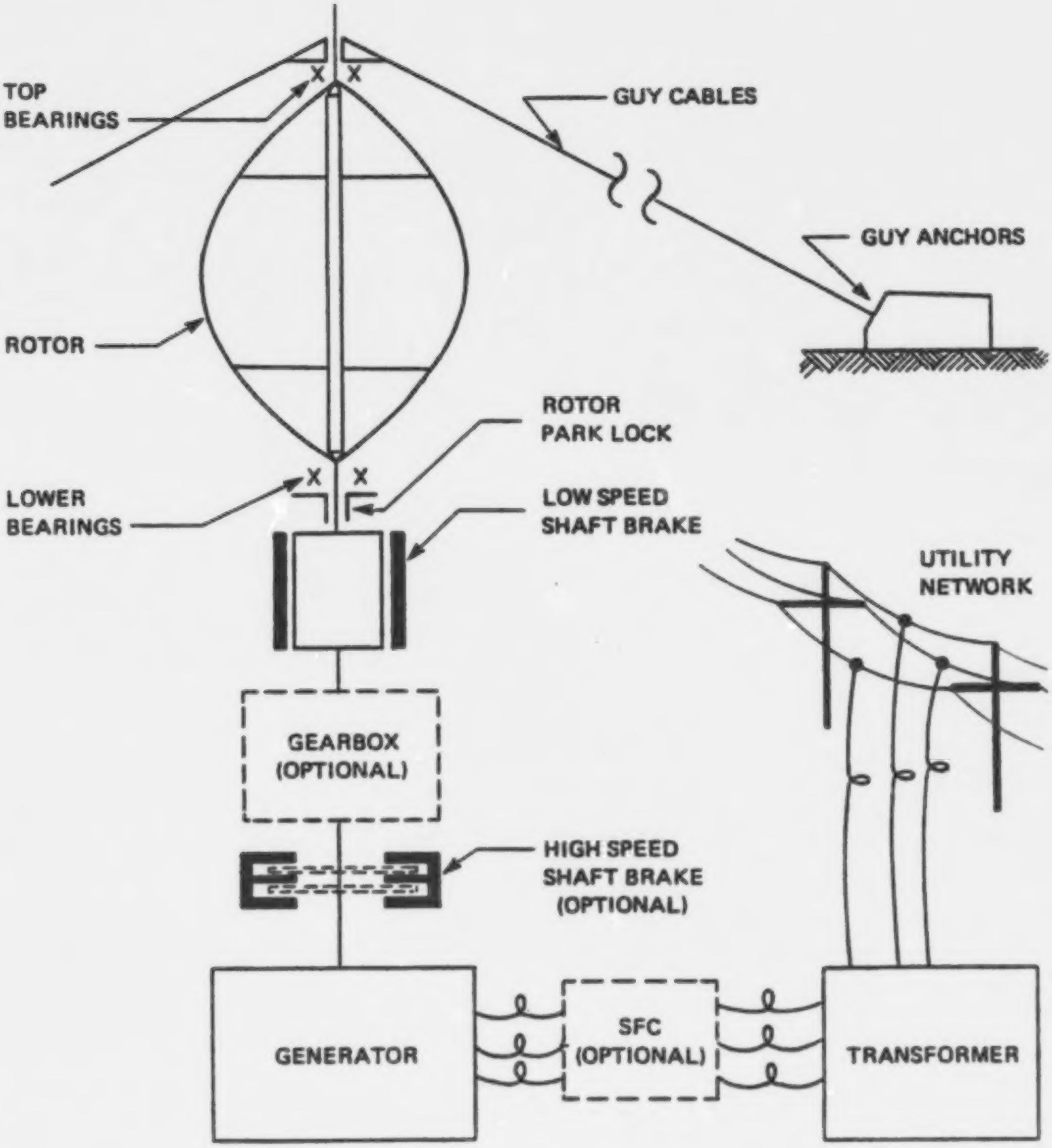
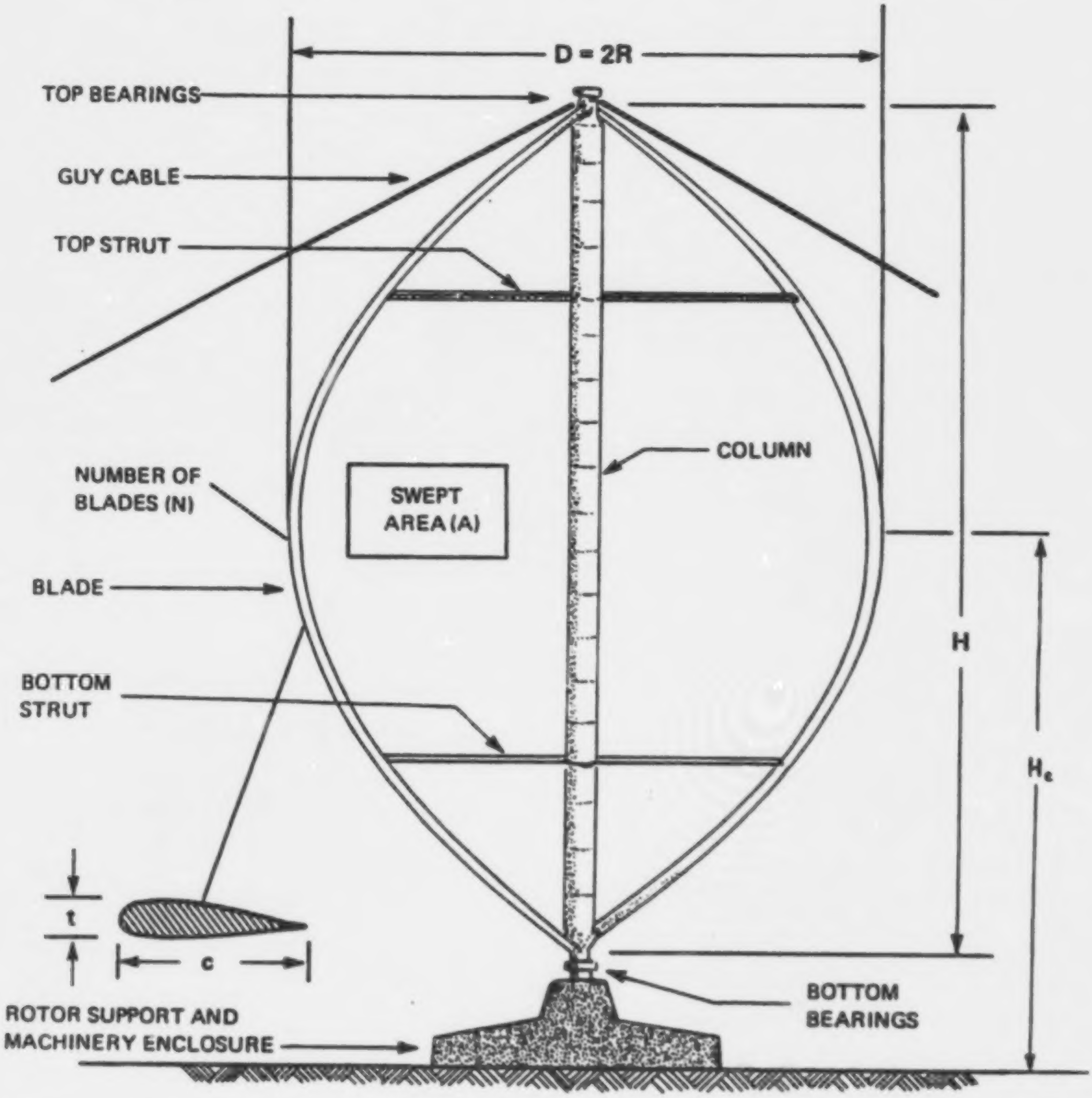

TOP BEARINGS
GUY CABLES
GUY ANCHORS
ROTOR
ROTOR PARK LOCK
LOWER BEARINGS
LOW SPEED SHAFT BRAKE
UTILITY NETWORK
GEARBOX (OPTIONAL)
HIGH SPEED SHAFT BRAKE (OPTIONAL)
GENERATOR
SFC (OPTIONAL)
TRANSFORMER

FIGURE 9 - EOLE – VAWTG SYSTEM SCHEMATIC


D = 2R
TOP BEARINGS
GUY CABLE
TOP STRUT
COLUMN
NUMBER OF BLADES (N)
SWEPT AREA (A)
BLADE
BOTTOM STRUT
H
H_c
t
c
BOTTOM BEARINGS
ROTOR SUPPORT AND MACHINERY ENCLOSURE

$A = 4000\ m^2$ $N = 2$
$H = 96\ m$ $t = 0.43\ m$
$D = 64\ m$ $c = 2.4\ m$

- air foil NACA 0018
- two bladed machine
- troposkein shape

FIGURE 10 - EOLE — COMPONENTS AND DIMENSIONS

FIGURE 11

EOLE GENERAL CHARACTERISTICS

Ambient conditions

Marine environment, -40 to 40 degrees C temperature range, seismic zone 3, ice load up to 60 mm at 0.9 density, wind maximum design 62 m/s.

Operating conditions

Cut-in 4.36 m/s, rated nominal 20.7 m/s, cut-out 27 m/s.

EOLE ROTOR CHARACTERISTICS

Overall dimensions

96 m high, 64 m wide at equator, 4000 square meter swept area.

Blades

2 blades NACA 0018, 2.4 m chordwise symmetrical profile, nominal troposkien.

Column

Cylindrical, 5 m diameter

Material

Blades and column: steel - 30 years design life.

Controls

Aerodynamic brakes system to safely slow down the revolutions in off-normal conditions.

EOLE ELECTRICAL CHARACTERISTICS

Generator

Type:

low frequency AC synchronous, rated 4 MW at 14.25 rpm.

Excitation and control:

static frequency converter.

Electrical control:

Starting, variable or set speed operation and breaking.

Grid conditions:

HQ standard quality of power on nearby 69 kV distribution, no black start capability, local and remote control modes. When the machine is integrated into Hydro Quebec's network, it should be controlled from Rimouski, about 100 miles away.

HYDRO-QUÉBEC

PROJET ÉOLE - Aérogénérateur à axe vertical de 4 MW, Cap-Chat, Québec

Document préparé par B. Tahmazian et J. Déry,
pour le «6th Annual Wind Energy Symposium»,
à Toronto, Ontario, le 7 novembre 1983.

INTRODUCTION

Le Conseil National de Recherches du Canada (CNRC) et l'Institut de Recherche d'Hydro-Québec (IREQ) ont déjà installé, aux Iles de la Madeleine, une éolienne de 230 kW (figure # 1). Forts de la réussite de cette expérience, ils ont poursuivi la recherche dans le domaine de l'énergie éolienne et ont conçu un aérogénérateur à axe vertical encore plus puissant, ÉOLE.

OBJECTIF

ÉOLE est un projet de recherche et développement dont l'objectif est de construire une éolienne de 4 mégawatts, reliée à un réseau électrique, et d'en évaluer le rendement en vue de créer un modèle de série et de mettre sur pied une industrie de grands aérogénérateurs à axe vertical (figure # 2). Ce projet, géré par Hydro-Québec, repose sur la conviction que le coût de l'électricité générée par des aérogénérateurs à axe vertical produits en série sera concurrentiel avec celui des autres moyens de production de l'électricité.

COÛT ET PROGRAMME

Le coût du projet ÉOLE se chiffre à 35,2 millions de dollars courants. Il est assumé à parts égales par le CNRC et Hydro-Québec. L'aérogénérateur sera prêt à fonctionner à l'automne de 1985. Des essais qui dureront plus d'un an débuteront à ce moment (figure # 3).

APPROCHE GÉNÉRALE

Pour s'assurer du respect des besoins de l'utilisateur, la responsabilité de la réalisation du projet a été intentionnellement confiée à une compagnie de services publics: Hydro-Québec. A l'intérieur d'Hydro-Québec, le projet a été confié à la direction Équipements de production. Les méthodes de travail employées dans des projets beaucoup plus importants en terme de complexité technique ou de coût ont été appliquées à ÉOLE. Cette approche qui transparaît à tous les niveaux du projet (organigramme, objectifs, normes, procédures, permis, études environnementales, choix techniques, etc.) impose peut-être un carcan au projet mais, par contre, assure un produit final conforme aux besoins et usages de l'exploitant.

Dans ce sens, les études de fiabilité, maintenabilité et disponibilité pour ÉOLE ainsi que le contrôle de la qualité sont incorporés à toutes les phases du projet; les équipements sont spécifiés en fonction de ce qui est disponible sur le marché et selon des normes éprouvées; les équipements sont choisis sur une base compétitive. La formation de l'exploitant fait partie du projet.

Pour rencontrer les exigences d'une centrale électrique, ÉOLE doit être compétitif à l'achat et produire de l'électricité de qualité conventionnelle en fonctionnant de façon fiable et sûre et en demandant un minimum d'entretien et d'inspection. Le coût de l'énergie produite doit être acceptable pour le lieu donné et l'opération de l'aérogénérateur doit demander des aptitudes et des connaissances correspondant aux qualifications moyennes pour cette catégorie d'employés.

Toutefois, pour rencontrer les objectifs du projet en général l'aérogénérateur est suréquipé d'instruments de mesure qui n'existeront pas nécessairement sur le modèle série.

ORGANISATION

L'organigramme du projet est montré à la figure # 4. L'administrateur du projet est responsable de marier harmonieusement le travail confié aux ingénieurs-conseils et manufacturiers (partie pratique) avec le travail des chercheurs (partie théorique) en passant par les normes et procédures d'Hydro-Québec (partie exploitation).

CHOIX DE L'EMPLACEMENT

Pour le choix de l'emplacement et l'obtention des permis gouvernementaux, des études techniques et environnementales poussées ont été faites telles que: conditions atmosphériques, interférences électromagnétiques, intégration au réseau, fondations, bruits, potentiel archéologique, habitat dispersé, collision des oiseaux migrateurs, tourisme, agriculture, aspect visuel, infrastructure de transport et de télécommunications, etc.

La consultation du public local a confirmé le choix pour l'emplacement à Cap-Chat, village côtier de la péninsule gaspésienne sur le Saint-Laurent (figure #5). L'emplacement se trouve approximativement à l'élévation 100 m; le climat est maritime, avec une vitesse moyenne annuelle de vent à l'équateur du rotor d'environ 9 m/s et la région est connue pour l'accumulation de verglas pendant la saison hivernale.

DESCRIPTION GÉNÉRALE

Aménagements au sol

Une aire d'exclusion d'environ 100 000 m² délimitée par une clôture reliant les ancrages des haubans limite l'accès à l'éolienne et aux trois modules préfabriqués contenant l'appareillage électrique et le contrôle. L'aménagement est complété par un réseau routier, des stationnements et des services conventionnels sanitaires, éclairage, etc. (figure # 6).

L'aérogérérateur

D'une hauteur de 110 mètres et maintenue à la verticale par six haubans, l'éolienne (figure # 7) repose sur une base en béton et entraîne une génératrice de 4 MW à 14,25 tours par minute par vent de 20,7 m/s.

La génératrice est du type synchrone basse fréquence AC en prise directe avec le rotor. Elle est couplée au réseau par un changeur de fréquence statique qui ondule à la fréquence du réseau et par un transformateur élévateur qui monte la tension au niveau du réseau (figure # 8).

L'aérogénérateur est à vitesse variable, ce qui est rendu possible par l'introduction du changeur de fréquence statique.

Le train d'entraînement qui relie le rotor à la génératrice est constitué essentiellement d'un pivot, un palier support, un frein mécanique et un accouplement flexible qui sont tous montés sur l'arbre.

Le contrôle de l'aérogénérateur

Le contrôle de l'aérogénérateur se fait par le changeur de fréquence statique. Il inclut le démarrage, la génération et le freinage à vitesses sélectionnées ou variables.

Conception modulaire

Les aérogénérateurs sont destinés à être installés en général dans des régions éloignées ou des terrains de faible valeur qui peuvent être difficiles d'accès; ÉOLE est conçu de façon à minimiser les travaux de chantier. Tous les équipements sont préassemblés et testés en usine; le travail de chantier consiste à monter les équipements et raccorder les interfaces. Une fois l'aérogénérateur installé, l'entretien doit pouvoir se faire avec des engins de manutention courants.

Exigences de sécurité

La sécurité du public et du personnel sont la considération première et la protection de l'équipement entre au second lieu.

La sécurité du public et du personnel en général est couverte en limitant la circulation à l'intérieur de la zone d'exclusion.

L'équipement est protégé par des dispositifs de contrôle qui permettent la survie. Le rotor se protège contre les survitesses par un système indépendant d'aérofreins. La génératrice se protège de façon conventionnelle par l'ouverture de ses disjoncteurs. Le haubanage à six haubans permet la perte totale de l'un d'eux sans mettre en danger l'aérogénérateur.

CHOIX TECHNIQUES PRÉLIMINAIRES

La configuration retenue est la résultante de choix techniques qui ont été faits tout le long du projet en collaboration avec le CNRC et l'IREQ.

De 1978 à 1980, des études techniques ont été faites pour permettre d'évaluer les grands aérogénérateurs pour la production d'énergie électrique. Une de ces études, confiée à une firme d'experts-conseils travaillant avec la collaboration d'un manufacturier, a comparé les aérogénérateurs à axe vertical avec des aérogénérateurs à axe horizontal. Parmi les conclusions de ces études, on retrouve les points suivants:

- La machine à axe vertical possède l'avantage d'être de conception relativement simple. En particulier, l'installation de la machinerie du train de transmission au niveau du sol n'impose que des contraintes minimales, au point de vue de l'agencement, des dimensions et des caractéristiques de l'équipement. Cette solution offre donc plus de latitude pour accroître la production et réduire le coût de l'énergie, tout en présentant d'importants avantages en termes de fiabilité, d'exploitation et d'entretien.

- Compte tenu de la précision des analyses, l'aérogénérateur à axe vertical est entièrement concurrentiel avec la machine à axe horizontal. Les données indiquent même qu'il lui est techniquement et économiquement supérieur.

Suite à ces études, une définition technique préliminaire a été produite en 1981 proposant la réalisation d'un aérogénérateur dont les caractéristiques générales sont présentées aux figures # 9 et # 10.

CHOIX TECHNIQUES LORS DE L'INGÉNIERIE

La figure # 11 montre les principales caractéristiques techniques actuelles du projet.

Aérofreins

Des aérofreins d'urgence ont été ajoutés sur le rotor pour agir en dernier recours et protéger le rotor en cas de perte de contrôle par la génératrice.

Choix des matériaux

L'aluminium, les matériaux composites et l'acier ont été considérés pour le rotor; l'acier a été retenu autant pour la colonne que pour les pales. Le choix a été fait sur une base économique pour le prototype.

Train de puissance

Le train de puissance comprend l'arbre de prise de force du rotor jusqu'à et y compris la génératrice. Il a fait l'objet d'une étude pour comparer la génératrice en prise directe avec la génératrice couplée au rotor au moyen d'un multiplicateur de vitesse. La génératrice en prise directe a été retenue sur la base de la supériorité technique dû à sa simplicité, son efficacité et sa fiabilité.

Vitesse variable

L'aérogénérateur à vitesse constante relié au réseau de distribution électrique a été comparé avec les avantages d'un lien asynchrone. Le lien asynchrone a été retenu pour le prototype à cause de sa supériorité. Ce lien permet le fonctionnement de l'aérogénérateur à vitesse variable qui nous permettra d'enrichir nos connaissances dans ce domaine et promet aussi un rendement de capture d'énergie supérieur. Le lien asynchrone est réalisé avec un changeur de fréquence statique qui ondule à la fréquence du réseau l'énergie produite à plus basse fréquence par la génératrice.

Nombre de haubans

Le nombre de haubans a été choisi en fonction de la stabilité du palier supérieur et aussi pour permettre un remplacement complet d'un hauban sans mettre en danger l'installation. Le nombre six a été retenu.

CONCLUSION

La configuration présentée est la résultante des choix techniques décidés jusqu'à présent. L'ingénierie suit son cours et certaines optimisations pourraient modifier cette configuration de base.

Grâce à notre approche méthodique et éprouvée sur d'autres projets majeurs et avec le support de ressources hautement spécialisées provenant des différents milieux de recherche scientifique, d'ingénieurs-conseils, de l'industrie et des services publics, le projet ÉOLE progresse conformément aux prévisions tant au niveau de contenu que coût et échéancier.

Les résultats obtenus jusqu'à présent sont très prometteurs et renforcent notre croyance en l'avenir de l'énergie éolienne et de l'aérogénérateur à axe vertical en particulier.

WIND ENERGY ACTIVITY REVIEW

Monique Carpentier, P. Eng.,
Wind Program Engineer
Energy, Mines and Resources Canada

Good morning ladies and gentlemen

My presentation is a a resume of a report done by my department entitled "Wind Energy Activity Review". This represents the first step in the process to refine the federal policy for the development of wind energy in Canada. This initial report will soon be available to the general public. I have brought copies with me if anyone wishes to have a copy today.

I will review briefly the major wind projects that have taken place in Canada and outline the position of the electric utilities toward wind energy and grid connection. I will also cover the provincial involvement in wind energy development, the wind energy industry in Canada, and finally the current EMR programs.

I am sure that many of you here today, already know all about those projects and programs and for you, this presentation may seem to be a collection of old news. But it has taken me several months of work, to put together so much information, and in bringing all these activities together I believe you may have a better understanding of wind energy in Canada and its future needs.

I would like to take this time to thank those of you, who have helped me with this report. Without the comments and assistance which I have recieved, this job would have been very difficult and frankly, the quality of the report would have suffered. Again my thanks to all of you.

The current policy is generally centred around programs in Research, Development and Demonstration mostly at NRC and EMR.

If any one is going to talk about wind energy in Canada, one must start with the major Canadian organisation involved in the wind energy: The National Reseach Council...

As many of you know, NRC is responsible for the direction and management of federal wind energy research development activities. Their wind program is comprised of three closely-integrated sub-programs:

1. Resource Assessment and Site Evaluation which is done mainly by the Atmospheric Environment Service of The Department of Environment.

2. Research and Technology Development and

3. Field Trials and Technical Support to Industry. NRC is involved directly or indirectly in many of the wind projects. As you will see, quite often its name will be mentioned during this presentation.

I would now like to speak about the major wind energy installations in Canada.

(SLIDES)

Let's start with what is probably the best known installation in Canada: The Atlantic Wind Test Site. The laboratory was officially opened in July 1980. It has been used to investigate and test small windmills in the range of 1 to 500 kW, although the site is capable of accommodating machines of any size and rating up to 2 MW. The AWTS is available to all Wind Energy Manufacturers who wish to test their machines.

To gain more experience with grid coupled installations, five 50 kW Darrieus machines have been purchased by NRC from DAF Indal, for co-operative field trial assessments with provincial electric utilities. These projects enable utility personnel to acquire first hand experience in operating and maintaining what is to them, an unconventional power plant.

There are, in fact, 4 sites and 5 wind turbines. They are located in Newfoundland, Saskatchewan, British Columbia and Manitoba. The Holyrood installation in Newfoundland was removed in November 1981 for detailed inspection and replaced with an updated unit. By August of this year these machines had accumulated over 24 thousand operating hours.

Another very important installation for remote application is the Wind/Diesel Hybrid system in Sudbury. The vertical axis turbine is mechanically coupled to a 50 kW diesel-electric site as part of a remote community powerplant. At the end of the intial phase of of the project, certain changes were recommended and the Sudbury II, an improved system, is now operating.

Another project consisted of 6 field trials of Darrieus machines under the Program for Industry/Laboratory Projects called PILP. The six Darrieus assisted with Savonius for starting were built by Bristol Aerospace. The design has proven to have several problems. There are still two windmills out in the field, but Bristol decided not to renew its request for a new grant from PILP in December 1982 and the whole project has been virtually shut down.

Now let's look at bigger installations:

The 230 kW turbine on Ile de la Madeleine is a cooperative project between NRC and the Institut de Recherche de l'Hydro-Quebec. This turbine was for several years, the world's largest vertical axis. As many of you remember, the rotor was destroyed in an accident in 1978. A new turbine which incorporates a few minor modifications was erected and the experimental testing was completed last December . Since January, the system has been operated in a semi-automatic mode by local Hydro-Quebec staff and is producing electricity for the island residents.

Project Aquilo, is the most recent project funded by the NRC. Project Aquilo is the name for the installation and testing at the AWTS of a 500 kW vertical machine made by DAF Indal. The system is now at the site and will be erected sometime next week. Aquilo will be the largest wind turbine in Canada until EOLE is built.

And finally there is the largest project, Project EOLE, which has already been described by Messrs. Tahmazian and Dery. I believe it's safe to say that many people around the world are waiting to see the results of this very ambitious project.

It's really nice to talk about all these installations, but what is the position of the electric utilities toward wind energy and grid connection. Well, in Canada the electrical utility situation is primarily organized on a provincial and municipal basis. They are not regulated by a federal agency as in the U.S.A.

If we speak about the United States, we often hear of the PURPA legislation, which is often perceived as being the best thing in the world for wind energy development. PURPA requires electric utilities to purchase electricity generated by small producers and also to pay the "avoided cost" rates for each kW-h produced. This avoided cost can be as high as 10 cents per kW-h in some states but also as low as 1 or 2 cents per kW-h in some other states. Coming back to the situation in Canada. Most of the major utilities are, at present, in the process of forming policies and regulations to handle small, privately-owned generating facilities.

Ontario, Alberta, British Columbia, Saskatchewan, Prince Edward Island, Nova Scotia, and New Brunswick are all accepting grid connection subject to basic requirements for safe installation and operation. However the Saskatchewan Power Corporation is the only one which will pay the same price for the energy feedback into their grid as the energy they are selling.

The Northern Canada Power Commission is also the only one that specifies that all excess power feedback to the grid will be at no cost to the commission. This obviously has a negative impact on the economics of wind generators in the area.

Manitoba, Quebec and Newfoundland don't have any policies for grid connection but appear to be willing to consider any proposals on a case by case basis.

It is generally agreed that if wind power plants are to form any significant part of Canada's electricity supply, they will have to be recognized by the utilities as being safe, relatively risk free, and capable of being operated and maintained without abnormal difficulty. In addition, the utilities will have to see the wind power plants as being compatible with their existing power system and being the most economic type of power generation to add to the system.

To help in this regard, the Canadian Electrical Association which is an organization representing the major electric utilities in Canada has already awarded contracts for several wind energy studies. The CEA which is funded by the electric utilites across Canada and by the federal Department of Energy, Mines and Resources has also expressed an interest in participating in bigger projects like wind farms and others.

PROVINCIAL INVOLVEMENT

Now let's have a look at the provincial involvement.

New Brunswick, Saskatchewan, Manitoba and the Yukon Territory are involved in wind energy only to the extent of the funding of some demonstration projects under the Federal/Provincial demonstration agreement called CREDA.

The Northwest Territories and British Columbia have published information books on wind energy potential.

Prince Edward Island is involved in wind energy because of the AWTS. The province of Quebec plays a significant role through the participation of Hydro-Quebec in large demonstration projects and by the research work done by some universities.

Newfoundland does not have any projects or regulations about wind energy but the Newfoundland telephone company is operating windmills for the telecommunication stations.

Nova Scotia has published a book on wind energy and with the Federal government, has jointly funded approximately 30 wind projects in that province.

Ontario is also preparing a wind book and has funded several demonstration projects. Their most recent project called "Small Wind Power Systems Testing", provides for the testing of small wind generators at the AWTS.

Finally, Alberta is doing some monitoring work and has two projects under construction. One is a large scale water pumping windmill and the other is the comparative testing of six small scale windmills for pumping water in the Lethbridge area.

WIND INDUSTRY IN CANADA

The wind industry ... what is the size of the wind industry in Canada? Well approximately 10 companies in Canada manufacture wind systems and half as many more are preparing to do so this year. Only one manufacturer of large wind systems exists at the moment, and most of you know the DAF Indal company.

There are eighteen small wind systems distributors and dealers in Canada. Embryonic wind energy engineering groups are starting to form within several Canadian industries which have the potential to become viable designers and manufacturers of windmills.

There are about 500 wind systems installed and in use in Canada. Nearly all are small wind systems, both water pumpers and generators. The rest are mainly turbine, which are employed in research, development and demonstration projects.

Finally I would like to talk about my department, Energy, Mines and Resources, and what it is doing in this area. It may be a surprise to some of you, but there are several large scale programs already in place which are largely open for wind energy applications.

CREDA

The Conservation and Renewable Energy Demonstration Agreement is a joint funding agreement between the Government of Canada and several provincial governments for the demonstration of conservation and renewable energy.

Up to last August, more than 42 million dollars have been spent on the federal portion of the program and about 1.2 million was spent on wind. The program offers funding assistance to demonstrations in either energy conservation or renewable energy and is aimed at the commercialization of these technologies.

The equivalent of CREDA in the province of Quebec is called Enerdemo, where the federal government directly delivers this program which started last June. 29 million dollars will be spent over the next 5 years in conservation and renewable energy projects which obviously includes wind.

RCDP

The Remote Communities Demostration Program is a 4-year, two-phase program providing funds and information to help reduce the use of oil in remote communities. RCDP is now in Phase I, funding studies up to the end of 1984. Phase II, which will begin in fiscal year 1983-84, will fund actual demonstrations which follow from the study phase.

At the moment, two wind studies have been approved (1 B.C. and 1 Ontario) and there are 4 more wind studies under consideration (2 Quebec, 1 Newfoundland and 1 Ontario).

For the immediate future I see many opportunities within the current programs which I have just described. These should be around for a few more years and while they are not solely dedicated to wind energy, such projects certainly will qualify and I strongly suggest that any of you in the business make yourself aware of the opportunities that exist. I have with me several brochures on these programs.

WHAT IS THE FUTURE FOR WIND ENERGY IN CANADA?

This is a difficult question to answer. We at EMR are starting to look at a strategic policy for wind energy development and hopefully there will be some answers soon. Certainly there are areas where improvements are needed if wind is to break into the energy market.

We have recently conducted an economic evaluation of wind generators and the results show that wind installations are already economic in areas where there is a high wind regime, high fuel costs and reasonable turbine cost. But this represents a limited market and even in these cases the wind turbine will most of the time need major repairs, and the operation and maintenance costs might be very high.

Therefore it is obvious that the product must first of all be improved. There already exists ways to improve it, through demonstration projects to test wind turbines in actual installations or on a test site. Windmills should also in the near future be built in accordance with the CSA standards which are under development. The preliminary standards should be available soon.

Another very important factor is the high capital cost, and efforts are being made in this area. Demonstration and R&D programs are both aimed at reducing costs. Financing also seems to be a problem within the industry. While I have no easy solution to this problem, I would like to suggest to the industry that you consider offering some sort of warranty with your product. In doing so, the perceived risk will be lower and perhaps investors or even utilities will be more enthusiastic about investing in wind energy.

It can be argued that the government incentives for wind energy development have not been as generous in Canada than in the United States, but the situation is not the same either. The cost of producing electricity is a lot cheaper here and most of the provincial utilities are facing a surplus of generating capacity rather than looking for more generating sources.

But I, personally, am optimistic about the future. Canada has the resource. It has numerous potential sites especially in remote areas. It also has the lead in the development of the vertical axis turbine. There are a lot of good ideas which are being developed which could lead to significant breakthroughs in this field.

There are certainly opportunities available and I hope to do my part to ensure that we have every chance of success. Thank you.

Q. What were the RCDP program studies that were approved?

A. Two have been approved in Quebec on the Magdalen islands. Others are one each in Newfoundland, B.C., and Ontario.

Q. Are there any changes in EMR policy regarding providing subsidy or tax credits to businesses who want to install wind systems? Is this being rectified?

A. Not really, not at the moment. I would like to point out that if any one of you has any good ideas about programs in wind energy or something that you would like to see, just give us a call and come see us. You will be welcome and also your ideas. Thank you very much.

"INDUSTRIAL AND REGIONAL DEVELOPMENT PROGRAM (IRDP)"

Marvin Bedward,
Incentives Officer,
Department of Regional Industrial Expansion

The Industrial and Regional Development Program is the federal government's fundamental tool to achieve Canadian industrial growth and productivity while reducing regional economic disparities.

Administered by the Department of Regional Industrial Expansion (DRIE), it is the first industrial development program that applies to every step in the industrial development and marketing process.

Combining the best elements of seven former programs in a simplified and streamlined form, IRDP has been tailored to pay particular attention to the needs of small and medium-sized businesses and to be sensitive to local and regional economic conditions.

Manufacturers, processors, and certain tourism operators in all of Canada are eligible. This is quite a bit different from previous programs where only certain types of industries or certain areas were eligible for assistance. We have divided the country into tiers. There are four tiers of assistance offered on a progressively increasing basis with the greatest support available in the most economically disadvantaged areas of the country.

IRDP has a streamlined delivery mechanism and has decentralized decision-making in the case of smaller projects. This will increase the availability and usefulness of the program for small and medium-sized businesses. The elements of the program can be applied to reflect local opportunities in each region.

Intended to support private sector initiatives, IRDP is aimed at projects, industries and technologies with the greatest potential for economic return, sustained growth and international competitiveness.

IRDP responds particularly to the need of small and medium-sized businesses and complements other federal programs and the Federal Business Development Bank. IRDP features of particular interest to such firms include:

- A simpler, more flexible program structure;
- Regionalized decision-making and program delivery for many projects;

- Eligibility for assistance by unincorporated entities;
- Broader support for consultants' studies and venture capital searches;
- Access, for small businesses, to innovation assistance for projects involving new products but not substantial risk;
- Support for marketing initiatives;
- For certain non-profit organizations, assistance to support manufacturing and processing operations, and certain tourism operations.

The Program Elements

Many worthwhile projects fail because assistance is not available at a specific stage in their growth. IRDP addresses this problem by providing a range of financial support including grants, contributions, repayable contributions, participation loans and loan guarantees over all the phases of a typical corporate production cycle. Our priority is to increase productivity as well as encourage private sector investment.

The elements of the program are:

- Industrial development climate
- Innovation
- Establishment
- Modernization/Expansion
- Marketing
- Restructuring

Since the assistance required depends on the nature of the project and the need for support, the program flexibility will enable this assistance to be tailored to the particular circumstances of the applicant.

Ontario, for example, is divided into tiers I, II, & III according to the manner in which we have established the tiers. Tier IV is the tier that has the maximum level of assistance available to it. Most of Ontario is tier I with fewer tier II's and still fewer tier III's. Peterborough is an example of a tier III location.

REGIONAL DESIGNATION

While the program is a national one, and support is available for all areas, not all areas of Canada enjoy the same economic prosperity. Accordingly, to further encourage and stimulate industrial activity in the more economically disadvantaged areas and to reduce the disparity between regions, enriched support is available to those more disadvantaged regions. Targeting support is achieved through the use of a "Development Index", based on a formula using Canadian government statistical data. Using 260 of Canada's census divisions as the basic unit, the level of unemployment, the level of personal income, and the provincial fiscal capacity were combined to provide an objective means of determining which regions of Canada are most in need of support. There are four tiers of assistance. There is generally greater support available in eastern Canada than in western Canada and Ontario.

Tier I represents a basic national level support. Tiers II, III, and IV provide progressively more assistance. The level of support indicated as available is the maximum and may not be the actual amount offered which can go anywhere from 25% TO 75% assistance. To find out in which tier you are located, please contact your nearest regional office.

The development index will be reviewed annually, but transitional arrangements will be provided for approved projects and applications in an advanced planning stage.

GENERAL PROGRAM DESIGNATION

Program Eligibility

Costs will not be eligible if a legal commitment has been made in their regard previous to the date upon which the Department receives the application.

Incrementality

No project may be supported unless it would not proceed, insofar as location, scope or timing are concerned, unless support is provided.

Commercial and Economic Viability

The project and persons undertaking the project must be considered to be economically and commercially viable within reasonable bounds of risk.

We receive many applicants where the proponent has no money. They are looking for assistance for a business just getting started. You may say, "If I had money, why would I come to you?" We are looking at participating in projects but not being the sole underwriter of them. The applicant should be commercially viable and have some resources of their own.

Significant Economic Benefits To Canada

The project and exploitation of the results of the project must represent significant net economic or social benefit to Canada within reasonable bounds of risk.

Therefore we would not support a project that is moving from one area in Canada to another area because there is really no net economic benefit to Canada.

Eligible Applicants

Individuals, associations, partnerships, co-operatives, bodies corporate, and non-profit organizations are eligible provided the project or activity is undertaken in Canada. Assistance available will depend on the type of project or activity.

Amount and Conditions of Program Support

Eligible projects will not necessarily be supported at the maximum levels. The minimum amount of financial support required for the project to proceed and for economic benefits to be maximized will be provided.

Targeting Program Support

Priorities will be set after consultations with the private sector and other interested persons. Project proposals will be ranked according to the priorities and the economic benefits of the project. Regional development considerations will be of paramount importance.

For example, for your particular industry, we would be consulting with NRC, EM&R, and associations such as DynamoGenesis Inc., to target the priorities of the IRDP for the support of wind energy in Canada.

Eligible Assets

Capital assets acquired prior to the date on which an application is received in the Department will not be considered when calculating eligible costs under the program.

In certain circumstances, commitments are made for perhaps 10% of the project prior to applications to the department. In this case we would disqualify the 10% commitment if it is deemed that the 10% commitment is not instrumental in making the project go ahead, then we could consider the balance as eligible for assistance. However, if your commitments indicate to us that you would go ahead whether you received assistance from us or not, then no assistance would be provided to the project at all.

The Decision-Making Process

Eligibility for support does not mean an automatic right to assistance. Projects are selected according to government priorities to ensure that government support, if given, will have the greatest possible impact and will yield the maximum return.

Each eligible project is assessed in relation to other projects and its priority is determined by benefits and regional impact expected to result.

Authority to approve smaller projects has been delegated to the regional offices of DRIE, thereby reducing the time required to reach a decision. Larger projects are reviewed from the national perspective in Ottawa and take a little longer to approve. Our regional office is the First Canadian Place, Toronto. By decentralizing the authority to approve smaller projects, we hope to in fact offer you a sixty day turnaround on most projects.

Elements, Eligibility and Assistance

The following tables contain information on the various elements of the IRDP, the projects eligible under each element and the maximum level of assistance available for each project under all four tiers of assistance.

Please note that these descriptions are a summary of more detailed regulations. For more complete information, please contact the nearest regional office of DRIE. They will also provide you with the brief two-page application form.

Element: Industrial Development Climate

To foster a supportive environment for investment, industrial development and innovation by assisting in the establishment of centres of specialized knowledge which will have significant and direct benefit to regional industrial development, and by supporting industrial development infrastructure in areas of economic disparity.

Eligible Projects

a) Assistance may be made available to economic, business, or technological institutes, municipal corporations, etc., for studies, scholarships and development of courses relating to industrial development, and for specialized services and information dissemination which benefits industrial development.

b) Assistance may be available for the establishment of non-profit centres or institutions that are expected to become financially self-supporting if the centre or institution carries on or supports work related to industrial development.

c) Infrastructure directly related to regional industrial development may be supported on a shared-cost basis with provinces or municipalities.

Maximum Level of Assistance

	Tier I	Tier II	Tier III	Tier IV
a)	Eligible	Eligible	Eligible	Eligible
b)	Eligible	Eligible	Eligible	Eligible
c)	Not Eligible	Eligible	Eligible	Eligible

Element: Innovation

To encourage the development of new products, new processes and to increase industrial productivity and international competitiveness through support of research and development projects which show promise of economic success or strategic importance to a region and which would not be undertaken without support.

Eligible Projects

a) Studies - Assistance may be made available toward the cost of hiring qualified consultants for studies on project feasibility, technology transfer, market research and venture capital search associated with prospective innovation projects.

Venture capital search is really a very new element for the department. If you come to us with a reasonable business plan for a project or idea, we can provide assistance for you to hire a consultant to help you to formulate your plans to raise funds.

b) Developing New Products or Processes - Assistance may be provided for projects to develop or demonstrate new or improved products or processes including pollution control. These must be scientifically feasible, entail significant technical risk and represent attractive prospects for commercial exploitation.

I should emphasize that our main goal is to provide assistance to exploit projects which build industry and not necessarily to do the preliminary research and development. We are more active in the development phase rather than the research phase. We leave the pure research to NRC and some of the programs under EM&R.

c) Developing Technological Capability - Projects for the improvement or expansion of technological capability which do not lead directly to identifiable sales may be supported if the technological capability is of strategic importance to the firm and the regional industrial development priorities of the government.

In a case where we have held a lead on certain technology and there is the fear of the lead being lost, we can provide assistance to strengthen that lead or strengthen that industry.

d) Development and Demonstration - Projects to develop or demonstrate new products or processes, but which do not entail significant technological risk may be supported in a way similar to those in section b) above. However, this assistance will be repayable upon successful commercial exploitation of the resulting product or process.

e) Design - Assistance may be made available for the design of a new, durable product, capable of being mass produced, that offers good prospects for commercial exploitation.

Maximum Level of Assistance

	Tier I	Tier II	Tier III	Tier IV
a)	50%	60%	75%	75%
b)	50%	60%	75%	75%
c)	50%	60%	75%	75%
d)	50%	60%	75%	75%
e)	50%	60%	75%	75%

Element: Establishment

To assist in the establishment of new production facilities in those regions which have a relatively higher economic disparity.

Eligible Projects

a) Studies - Funding may be provided toward the cost of hiring qualified consultants for studies of project feasibility, market research or venture capital search associated with a prospective establishment project.

b) Plant Establishment - Funding may be made available for the establishment of new facilities for manufacturing or processing, tourism or selected service industry operations.

Maximum Level of Assistance

	Tier I	Tier II	Tier III	Tier IV
a)	50%	60%	70%	75%
b)	NIL	35%	50%	60%
	Special Tier I 35% *			

* Special Tier I - If the unemployment insurance beneficiaries-to-population ratio for a Tier I region exceeds the national average by one percentage point for any consecutive six month period, that region will be eligible for Tier II assistance for establishment for one year. Applications will be accepted during the year following the six month period.

Tier I's are not eligible for assistance to establish new companies because in these areas it is believed that there is already a reasonable infrastructure in place to provide the necessary resources to establish the firm.

The maximum approved capitals costs to be eligible for assistance under b) above have been established as:

Tier Group	Establishment
I	N/A
I (Special)	$50,000.
II	$50,000.
III	$25,000.
IV	$5,000.

Element: Modernization/Expansion

To increase industrial productivity through the improvement, modernization and expansion of existing commercial operations.

Eligible Projects

a) Studies - Assistance may be provided toward the cost of hiring qualified consultants for project feasiblility and other studies, market research and venture capital search for projects associated with modernization, productivity improvement or expansion.

b) Modernization - Assistance may be made available for the acquisition of new, advanced machinery and equipment which modernize or significantly enhance the productivity of existing activities in manufacturing and processing, tourism, and selected service operations.

c) Expansion - Assistance with the expansion of existing manufacturing or processing, tourism and selected service facilities.

d) Funding may be provided to manufacturers and processors for the first installation of micro-electronic devices in their products and operations, for the design of custom microelectronic devices, and for incorporation or application of electronic dependent products or systems in products, processes, production methods or facilities.

Maximum Level of Assistance

	Tier I	Tier II	Tier III	Tier IV
a)	50%	60%	75%	75%
b)	25%	35%	50%	50%
c)	25%	35%	50%	50%
d)	50%	60%	75%	75%

The minimum approved capital costs to be eligible for assistance under b) and c) above have been established as:

Tier Group	Modernization/Expansion
I	$100,000.
II	$50,000.
III	$25,000.
IV	$5,000.

Element: Restructuring

To assist firms and industries to make investments which adjust to changing competitive conditions and produce new, more viable and competitive products and services.

This one we apply very sparingly.

Eligible Projects

a) Studies - Assistance may be provided toward the cost of hiring consultants for studies of project feasibility, market research and venture capital search associated with prospective restructuring projects.

By restructuring we mean new financing or working capital. For example, a company goes out of business and a group of the employees wants to re-activate it, so assistance is needed to buy it out.

b) Loan guarantees of up to 90 per cent may be provided for restructuring projects. An annual guarantee fee will be levied.

Restructuring of payables or participation loans are seldom used. Furthermore, we do not like to use them. It is probably the most difficult program element for which to obtain any assistance from our department.

Projects involving loans of less than $500,000 will normally be referred to the Federal Business Development Bank (FBDB) which can better serve this level of business clientele through its direct lending activities.

Loans of over $500,000. are referred to Ottawa and the process is an arduous one. I would not recommend pursuing unless in dire straits. It is very difficult to gain access to that level of assistance.

c) Repayable contributions of up to 25 per cent may be provided for restructuring projects.

d) Participation loans not exceeding 15 years may be provided for restructuring projects.

Maximum Level of Assistance

	Tier I	Tier II	Tier III	Tier IV
a)	50%	60%	75%	75%
b)	Eligible	Eligible	Eligible	Eligible
c)	25%	25%	25%	25%
d)	Not Eligible	Eligible	Eligible	Eligible

Element: Marketing

This section refers mainly to non-profit organizations and tourism operations.

To facilitate the identification, development and exploitation of new domestic and international market opportunities, and to enhance competitiveness within existing markets.

For certain cases of non-profit organizations we can provide higher than the tier maximum level of assistance depending upon the benefit that we feel can be derived.

Eligible Projects

a) Assistance may be made available to persons carrying on or about to carry on a tourism operation for the collection and dissemination of information for the purpose of developing its market, for arranging a special event likely to attract tourists, and for organizing conferences likely to result in a subtantial increase in tourists or visitors.

b) Assistance may be available to economic, business or technological centres and similar non-profit organizations for activities promoting the acceptance of Canadian standards and product specifications, for market research and analysis, trade shows or other events or for the publication and dissemination of catalogues to promote Canadian products if the purpose is to increase the marketing of products or services of commercial operations.

c) Studies - Funding may be available toward the cost of hiring qualified consultants for feasibility studies for the above as well as toward the cost of market research and marketing strategy studies for a) above.

d) Assistance may be made available for arranging special events, conferences or major meetings where the purpose is to increase marketing of the products or services of tourism operations.

e) Program for Export Market Development (PEMD) - Although not part of IRDP, PEMD will be delivered by DRIE on behalf of the Department of External Affairs in support of DRIE's continuing responsibility for trade promotion in Canada.

Maximum Level of Assistance

	Tier I	Tier II	Tier III	Tier IV
a)	50%	60%	75%	75%
b)	Eligible	Eligible	Eligible	Eligible
c)	50%	60%	75%	75%
d)	Eligible	Eligible	Eligible	Eligible
e)	Eligible	Eligible	Eligible	Eligible

Q. What type of advantage has been taken of this program? Could you give us an example of a project that the program could reach?

A. There are no typical examples. A frequent request is for assistance to expand existing operations. Expansion is usually the purchase of additional machinery or equipment and could include the addition or renovation of existing facilities to accommodate the new machinery or equipment. As mentioned before there are differing levels of assistance available according to the tier in which the project is located. However, unless the company has a clearly demonstrated need for the maximum level of assistance, the department would consider a funding level starting at approximately 60% of the maximum for the tier. There are examples where a foreign company might wish to establish in Ontario. Again, the assistance for establishment, that is the costs to buy machinery, equipment, building and certain pre-production costs that are capitalizable, will be judged according to the merits of each project and will likely be less than the maximum of the specific tier.

Q. Is there any stipulation with regards to Canadian content?

A. Yes there is. As much as possible we encourage the use of Canadian sources for the plant material. If the technology is available in Canada, we would like to develop the technology to manufacture in Canada. For example, if you developed a technology which you then wished to licence for manufacture in the United States or elsewhere, it would not likely be supported under this program because we are really looking to develop Canadian manufacturing facilities.

Q. Are there other government agencies which participate in funding projects?

A. We do participate with other government agencies. However, the assistance from all levels of government cannot exceed the maximum tier level of assistance available under IRDP. Let's say, we are providing 35% assistance to a company wishing to locate in a tier II area and the total government assistance exceeded that 35%. Our assistance would be cut back in order to bring it in line with the 35% maximum.

Thank you.

WIND POWER PROGRAM

Bill Stewart, P. Eng.
Ontario Ministry of Energy

With the sudden increase in oil prices and uncertainty in supplies coming as a result of the 1970's oil embargo, many countries identified the need to shift energy dependence more to domestic sources. The Ontario Ministry of Energy adopted a strategy similar to the Canadian government's National Energy Program with the main goals being to improve energy security and reduce oil consumption through substitution with alternatives such as renewable resources and through conservation. Thus Renewable Energy and Conservation groups were established in our Ministry.

The Remote Power Unit of our Alternative and Renewable Energy Group is concerned with the development and demonstration of those technologies which are suitable for use in remote areas of the province, but may need more development before commercialization. These technologies may not be cost competitive in Southern Ontario, but do look favourable when considered for remote locations away from the provincial grid where conventional fuels are usually very costly. The technologies include small hydro, small wood gasification, wood fired steam engines, wind power and energy conservation techniques for remote buildings.

Before developing any technology, a market must be identified, and the existence of this market will be determined strongly by the technical and economic viability of the technology. Wind power, for example, is rarely economic when compared to local energy sources in Ontario. However, when compared to the energy sources in remote Ontario, a potential market definitely exists. Therefore, remote locations provide the needed environment in which to develop, refine and commercialize the technology. There are potential markets in outside countries as well, especially developing countries, where the costs of conventional fuels or electricity are high enough to make alternatives such as wind power look attractive.

The Ministry's first important look at the wind power market and the technical and economic viability of existing technology was a study performed by the Ontario Research Foundation (ORF) in 1975. The results of the study indicated that wind power looked viable in remote locations experiencing high fuel costs and high winds, mainly in communities on or near the Hudson and James Bay coasts.

In response to one of the recommendations of the ORF study, the Ministry tested a small wind-diesel hybrid generating system on Toronto Island in 1977/78. The project showed the wind-diesel concept to be sound and compared two methods of connection of the wind turbine to the diesel, mechanical connection between the wind turbine shaft and the diesel engine shaft and electrical coupling of the wind turbine/generator to the diesel generator. The results indicated that wind-diesel was viable and that mechanical coupling showed advantages in terms of efficiency and simplicity.

The next step in the wind-diesel program was to demonstrate a system that could be readily commercialized. Thus, in 1981/82 with funding assistance from our Ministry and Energy, Mines and Resources Canada under the CREDA program, as well as funding from the National Research Council of Canada and Ontario Hydro, the contractor DAF Indal installed and operated a 100 kW wind-diesel, mechanically coupled system in Sudbury, Ontario. The final report for the demonstration is now being prepared. The system performed well, in fact very close to the predicted performance. For the duration of the demonstration period, the system saved about 10% fuel at an average wind speed of 5.4 m/sec. The system is designed to save from about 9% to 25% fuel depending on the wind regime. The main observation of interest during the demonstration period was the wind turbine displayed greater operational reliability than the diesel.

Presently we are testing modifications to the Sudbury system to further improve the fuel savings and allow the capability to retrofit to existing diesel plants. The wind generator will be allowed to operate independently of the diesel during favourable wind and load conditions, thus saving fuel and wear-and-tear on the diesel. In order to allow retrofit capability, the electrical coupling method will be tested. The stand-alone mode is expected to save an additional 2-20% fuel (depending again on the wind regime) without significantly affecting the system capital cost.

Also, we are currently formulating plans to set up a first-time demonstration of the wind-diesel system in a remote community in Ontario. Ontario Hydro will be carrying out a feasibility study of the most suitable sites. The communities to be studied are Fort Severn, Winisk, Fort Albany and Attawapiskat which lie on the Hudson and James Bay coasts. The Sudbury system employing the 50 kW wind rotor or a new system employing a 375 kW rotor are the options available. The 50 kW rotor (without diesels) would typically cost $190-210 thousand installed in a remote community and the 375 kW rotor, $730-750 thousand installed. Anticipated payback periods for such systems range from 14 years in the James Bay communities (Fort Albany and Attawapiskat) to 11 years in the Hudson Bay communities (Fort Severn and Winisk).

The wind-diesel program gives an approach to utilizing wind power in the larger of the diesel base communities, in remote industries and in remote government or commercial facilites. However, there are also small communities, farms, small commercial or government buildings or other remote dwellings or stations which may or may not have diesel generation. In these types of situations, a small stand-alone wind generator is often the best option.

In this regard, we are testing, demonstrating and transferring operating data on systems in the 5-20 kW rating range suited for such applications as small community electrical needs, farm operations and single dwelling heating requirements. As well, we are working with systems rated under 5 kW suited for the electrical needs of cottages, small buildings and remote weather or telecom stations.

As part of this program, a 10 kW DC (with battery storage) system was first tested out at the Atlantic Wind Test Site in Prince Edward Island and then installed at the Kortright Centre for Conservation north of Toronto. It is being used for public demonstration and as an educational tool at the Centre. The system was manufactured and installed by Wellington Windpower of Wellington, Ontario. This system is suited for remote, attended operation and has shown to be simple and durable. It is a three bladed horizontal axis turbine, 9 meters in diameter, with blade feathering using centrifugal weights, manual shutdown by rotor furling, and a brushless alternator supplying AC power through a rectifier to produce DC. The complete system to run a stand-alone load would typically cost $30-40 thousand installed in a remote location.

The real test for this type of wind power system will of course be in a remote setting where extreme temperatures, icing and high winds prevail. Presently, we are working with the Ontario Ministry of Natural Resources to assess the feasibility of implementing wind power in one of Natural Resources's remote offices. The office is situated near the community of Winisk on the coast of Hudson Bay. If the study is favourable then consideration will be given to installing and demonstrating a system.

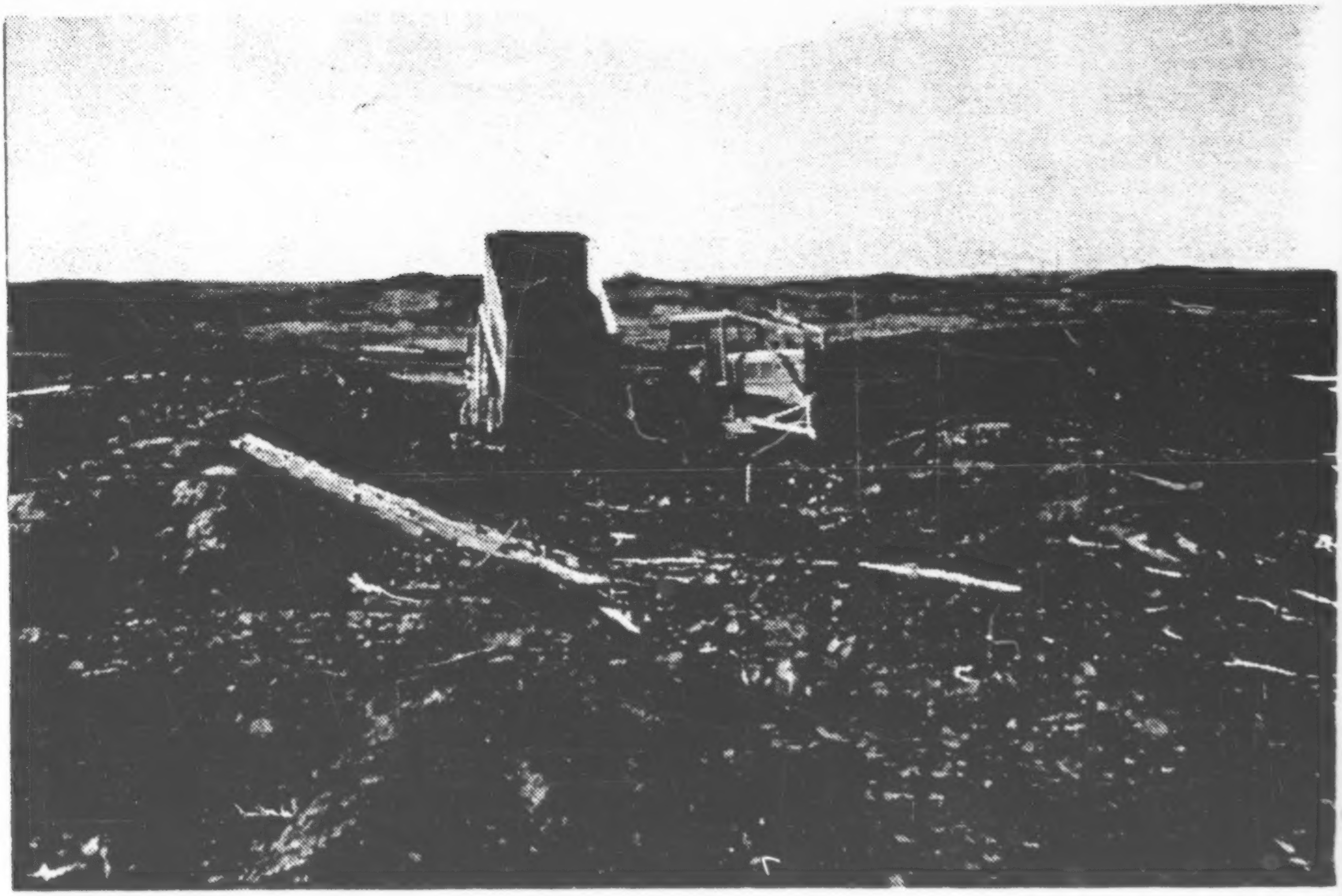
Smaller Canadian manufactured wind systems under 5 kW rating are now being assessed with the help of Resource Ventures of Charlottetown, P.E.I. and three or four systems will be chosen to be tested at the Atlantic Wind Test Site. Although the number of Canadian manufacturers of small wind systems is small, there appear to be a few which are developing good quality systems at prices which can compete with imported systems.

In addition to the role of helping to develop technologies, our Ministry must also lead in encouraging the adoption of renewable energy. Public demonstration of operating systems is one important component of communicating the viability and worth of the systems. As well, there is also the need to present information and data on programs and technologies through such media as symposia like this one and through written, published material.

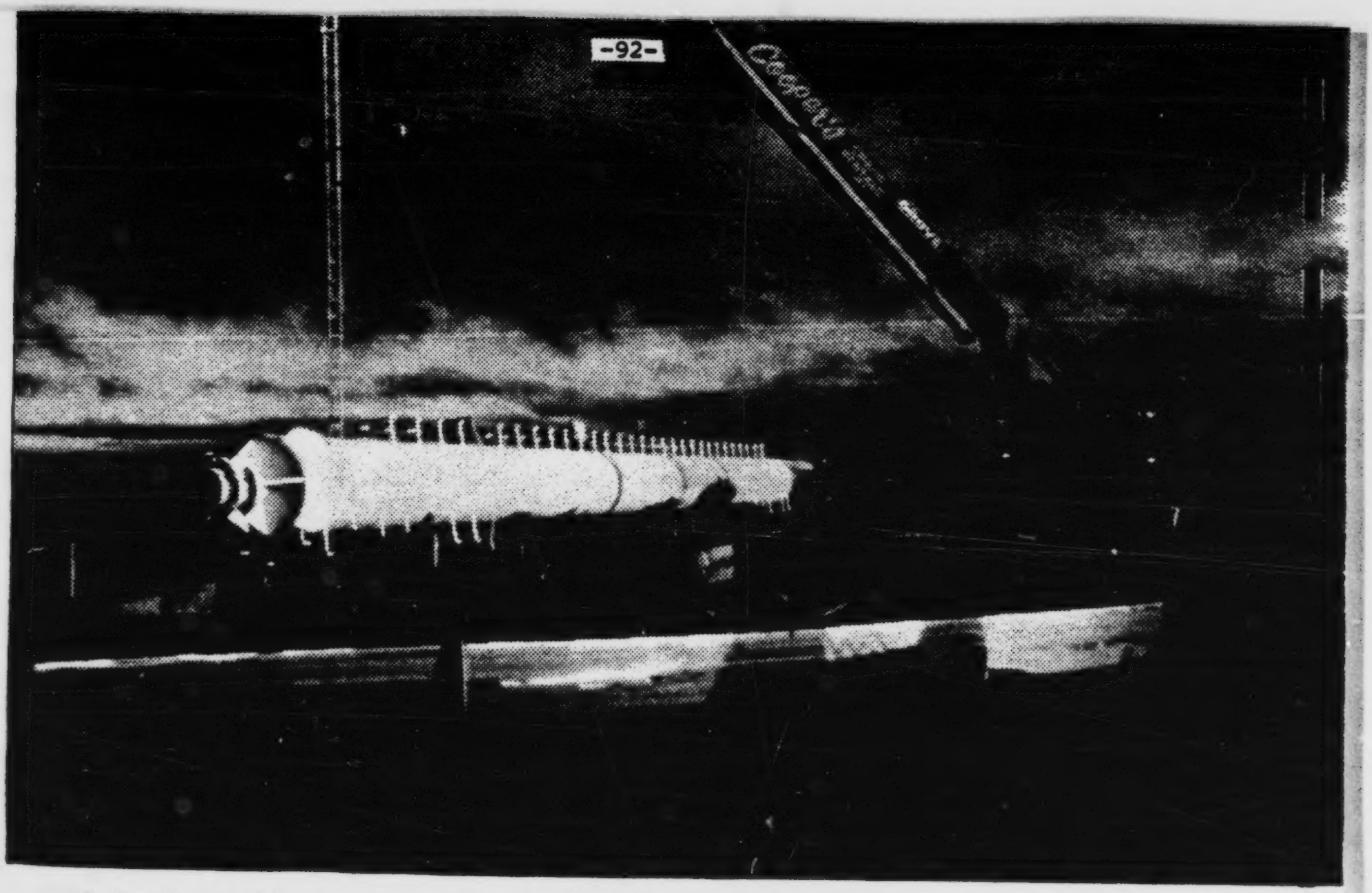
Results of the Toronto Island wind-diesel experiment are available from our government bookstore, as well as the 4th

Annual Wind Symposium Proceedings. We expect to publish the results of the first phase of the Sudbury project early next year. The testing results of the Wellington Windpower machine and initial results of the demonstration at Kortright will be made available next year. A handbook to help potential users assess the requirements and worth of installing a wind power system is being prepared and will be published next year.

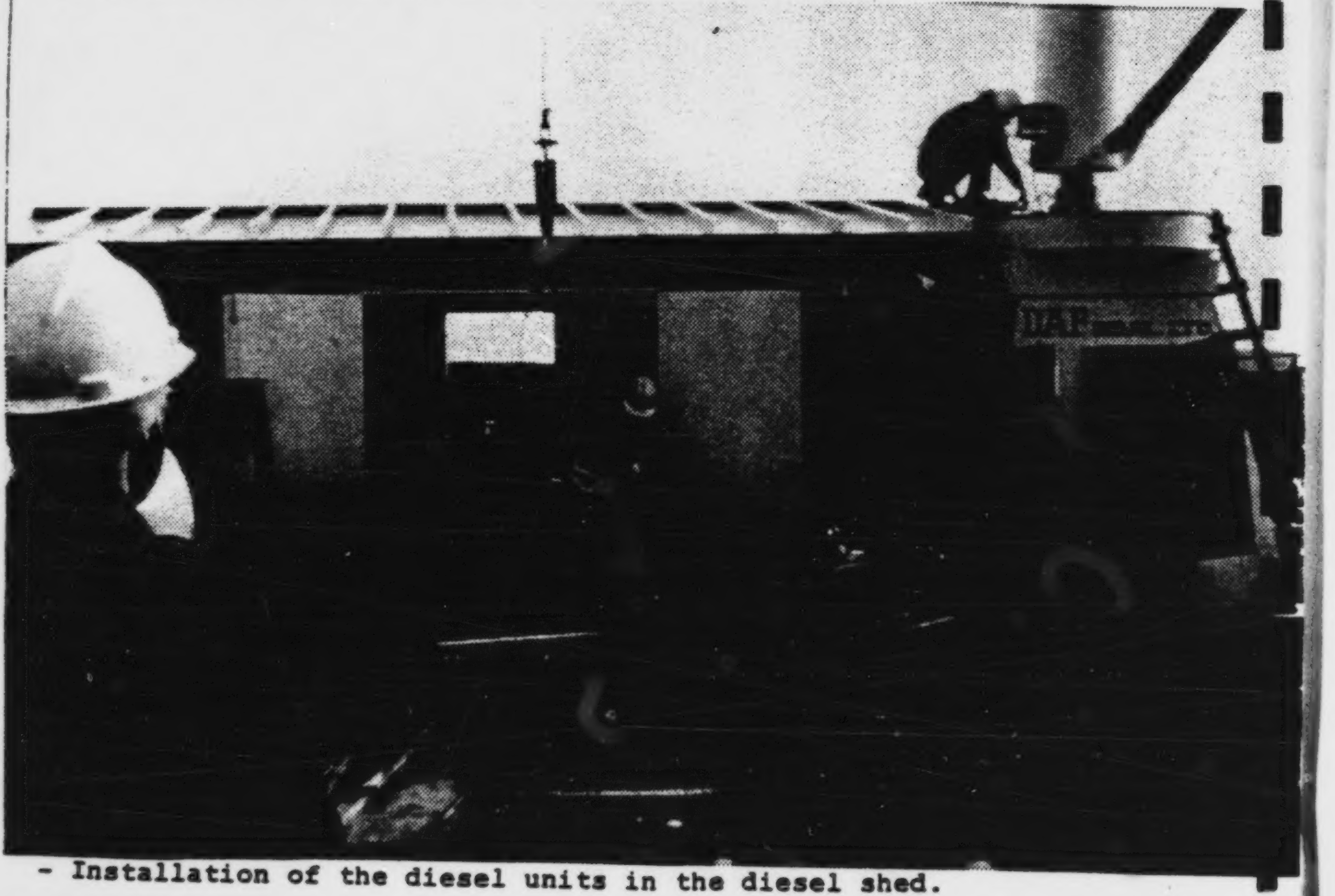
(SLIDES)



- Sudbury site before system installation. Quite barren, an ideal wind site.

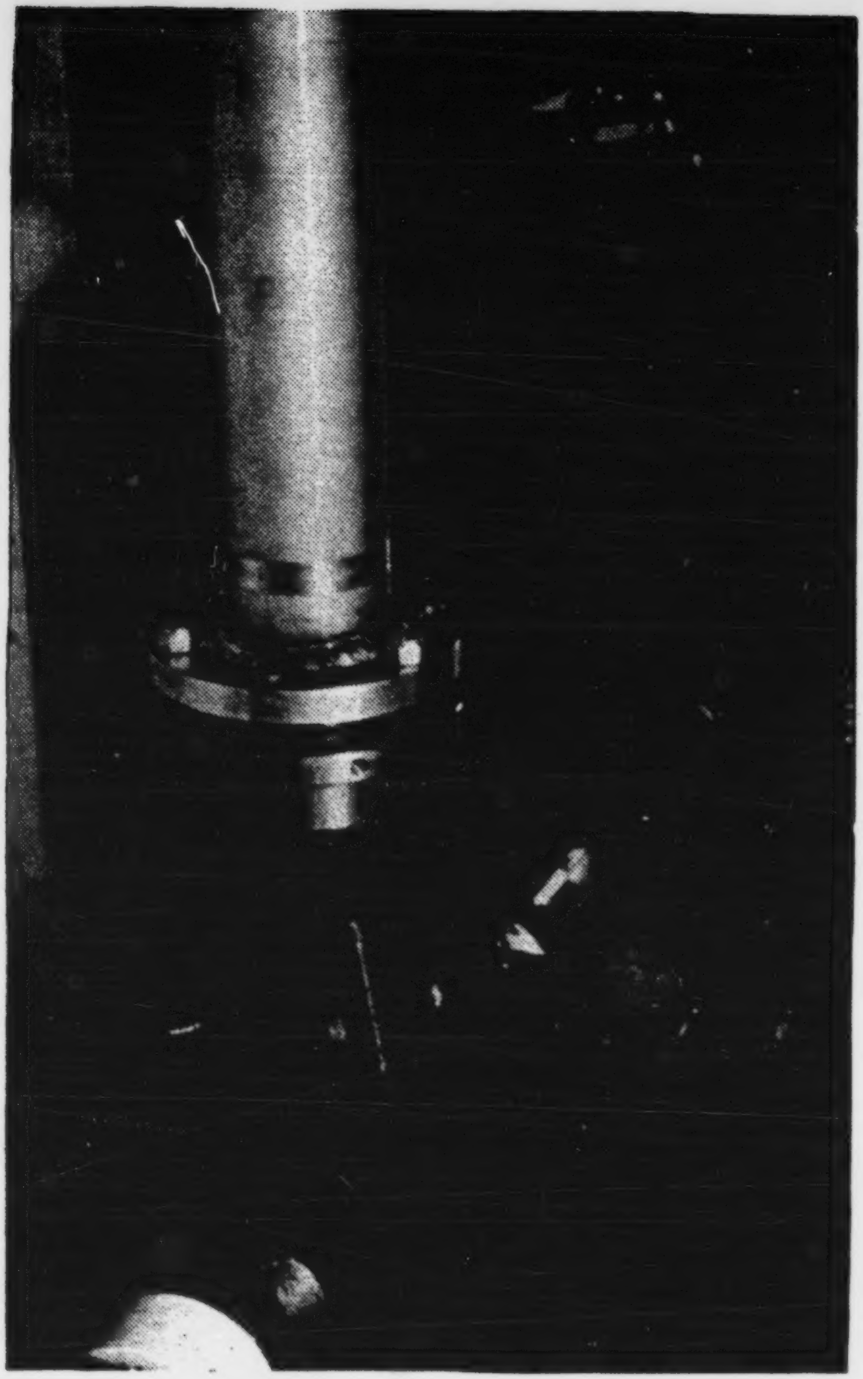


- A look at the components of the 50 kW DAF rotor.

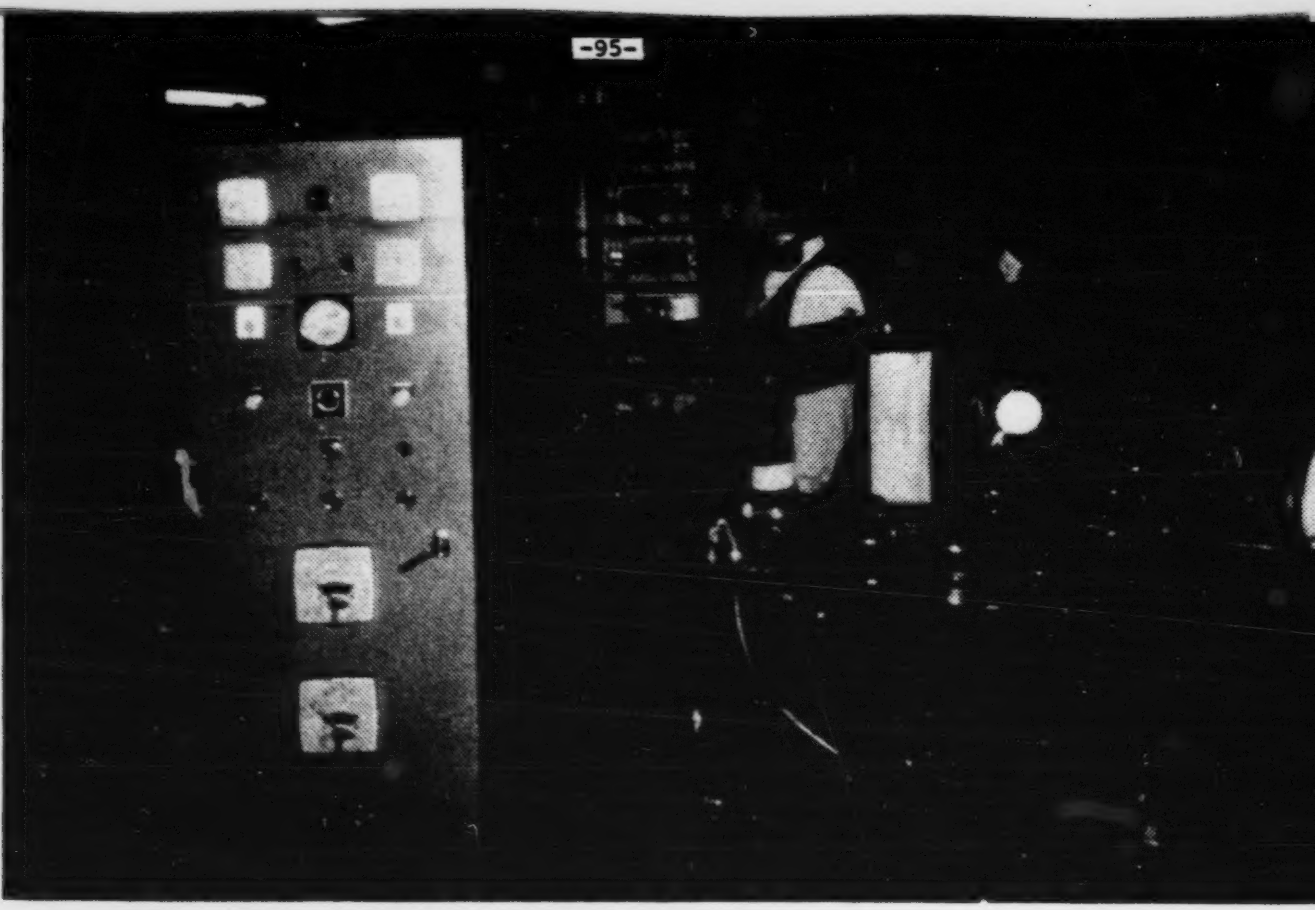


- Installation of the diesel units in the diesel shed.

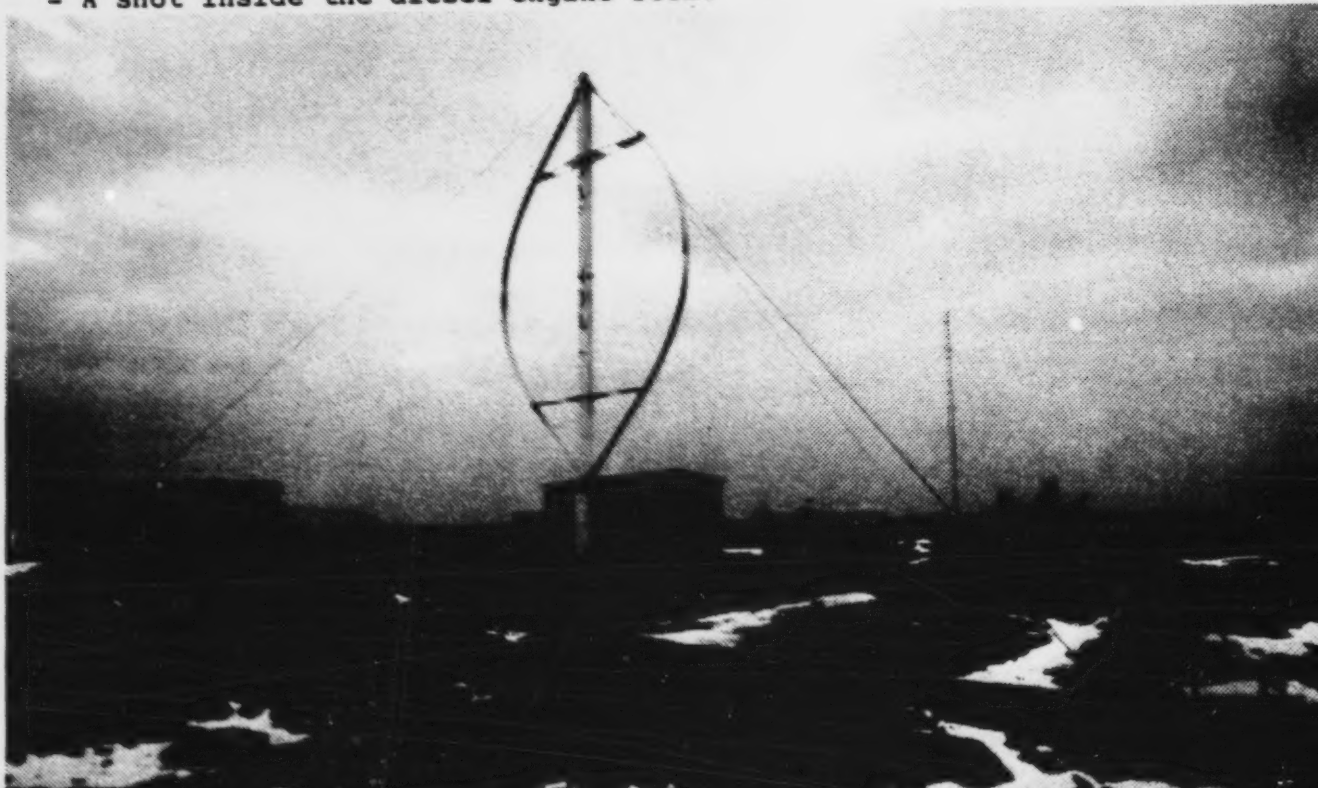
- Erection of the rotor using a crane.



- This shows the right angled coupling. The silver shaft is the low speed shaft from the wind turbine. On the left is the starter motor. on the right is the coupling to the alternator of the diesel engine.

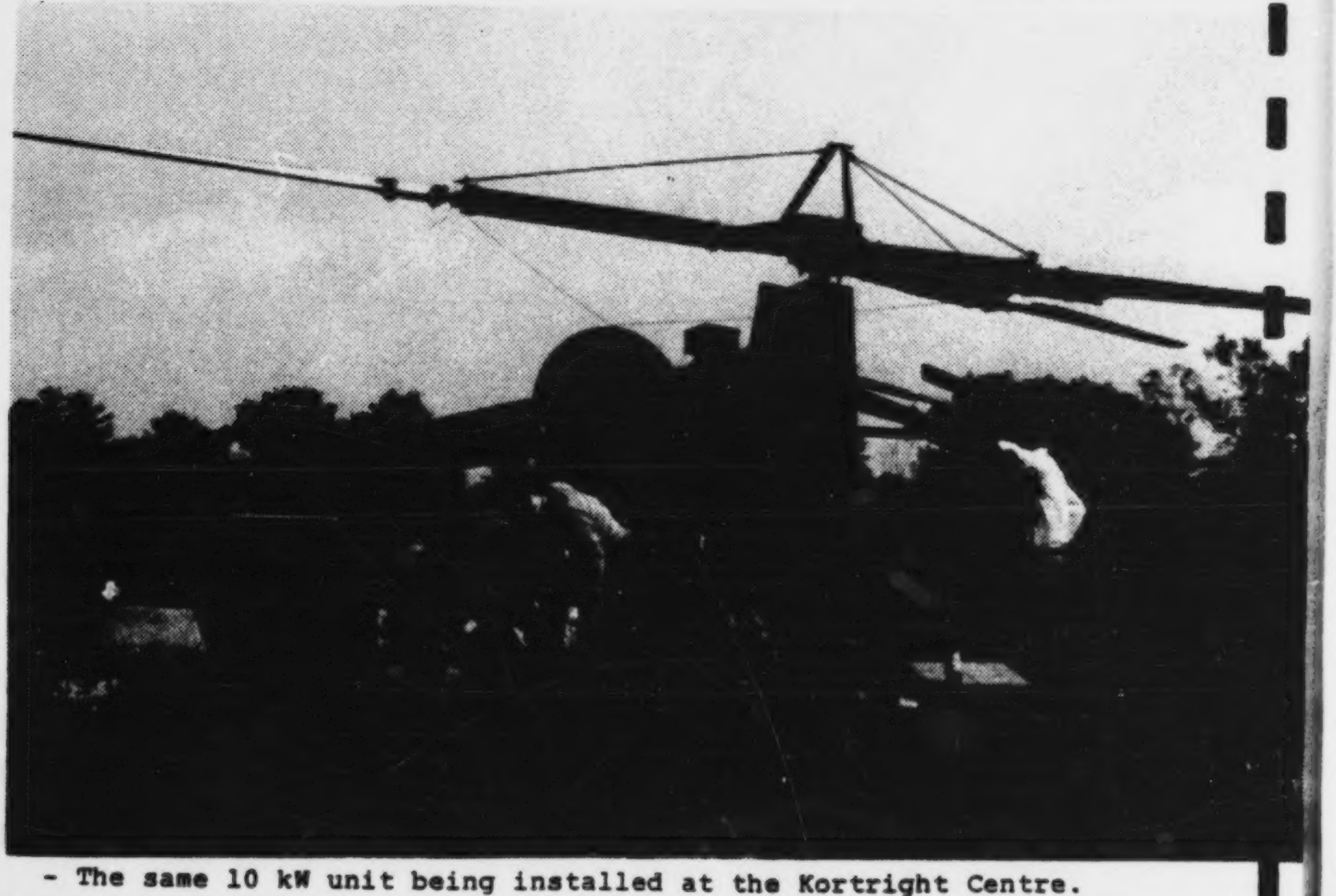


- A shot inside the diesel engine room.



- A look at the complete system. The building on the left is the control building.

- The Wellington Windpower 10 kW unit installed at the AWTS where it was tested.



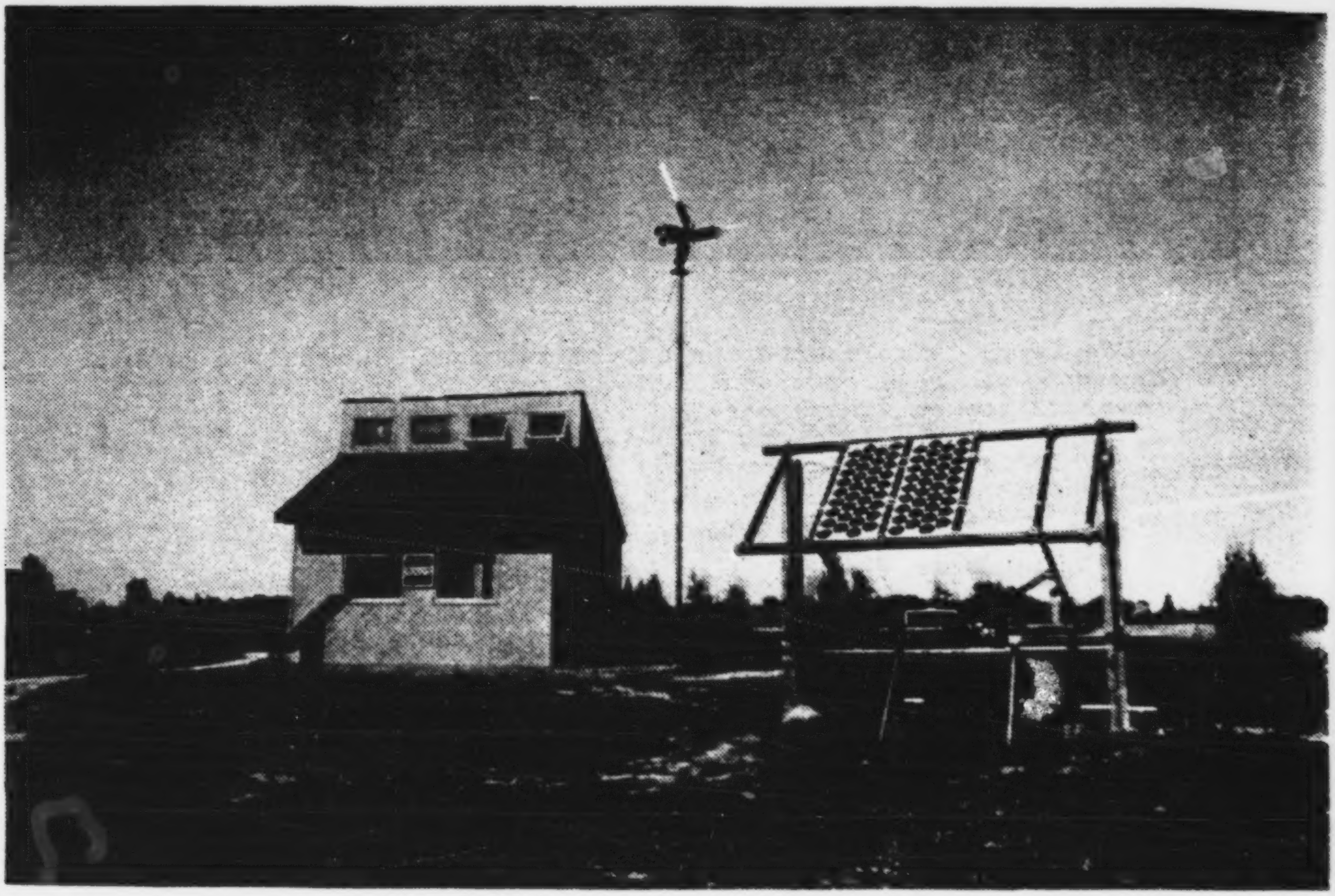
- The same 10 kW unit being installed at the Kortright Centre.

Q. I understand that the Wellington unit was redesigned after testing at the AWTS. Could you elaborate on that?

A. There were a couple of problems. One was in the hub of the furling mechanism. It was just a matter of making minor adjustments and replacing a pin. There was a slight problem with the voltage sensing relay chattering in the electrical control system. These were minor problems identified by the testing program and corrected by the manufacturer before the installation at Kortright.

Q. What are the capital and installation costs for the program?

A. This machine costs about $20,000. - $25,000. which includes the tower and battery system. We put a total of $50,000. into the whole project. including the test at AWTS and the demonstration at Kortright.



- A look at the complete 10 kW D.C. system set up. The building houses the batteries and control system. The photovoltaic panels supply power for the monitoring equipment for the wind system.

- The fairly simple erection of the turbine. Normally a tractor or truck can be used to pull up the tower in short time. The tower is hinged at the base.

Q. What is the tower height?

A. Sixty feet.

Q. What is the average site windspeed?

A. According to local MET station data, the average for the region at 10 meters is about 9 mph. The site has a venturi effect and the hub height is a bit higher.

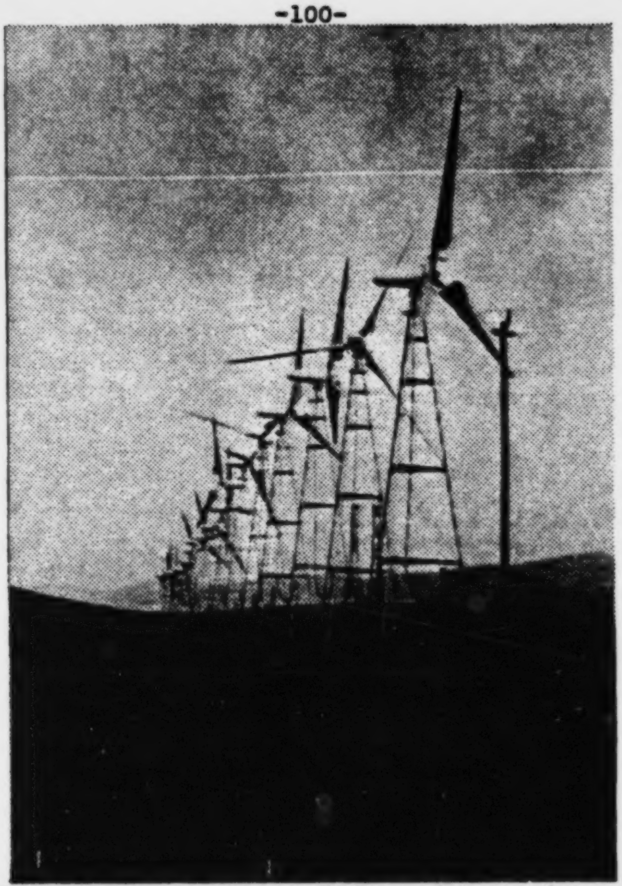
"SOME THOUGHTS ON QUANTITY PRODUCTION IN THE WIND TURBINE INDUSTRY"

Woody Stoddard, Phd.
Pioneer Wind Power Inc.,
Massachusetts

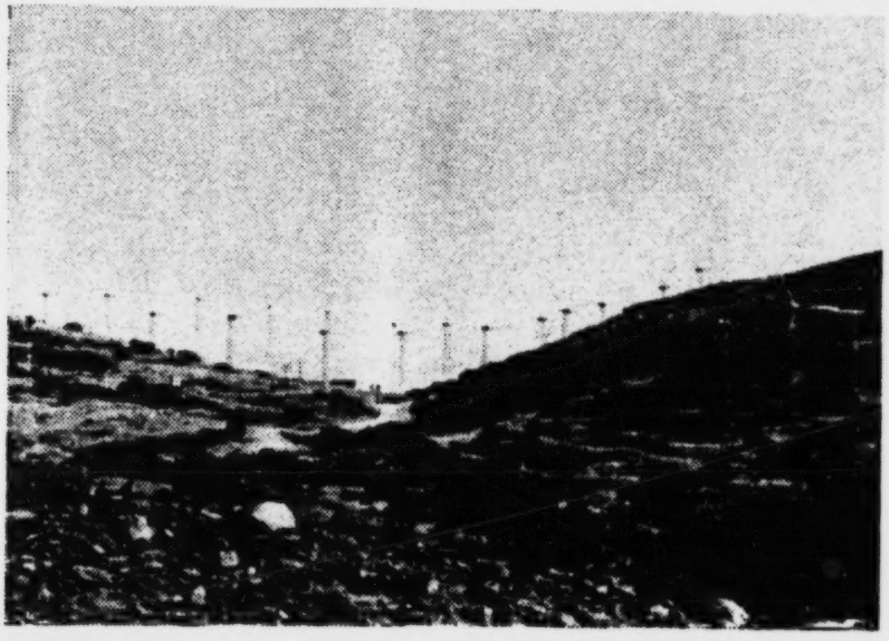
I spent a lot of my formative professional years as an ivory tower academic, listening to computer simulations and believing all the numbers that they spit out. For the past four or five years I have found myself going back to the trenches and one by one throwing out most of the theories that we developed for helicopters. They don't apply to these turbines that we are looking at. We can be as much as two hundred per cent off in the prediction of stresses. This causes us no end of concern because it is hard to reconstruct a failure in the field.

My company is a consulting group and we are asked to recommend fixes to wind turbines, generally far too late, when there is a generic problem and there are a lot of broken blades on the ground. This talk is going to be a little down beat. The reason is that out of all the turbines that we have operating in wind farms, and this will be mostly about wind farms because that's where the action is, there aren't very many that are working very well. There are some trends that I'll try to point out that we see, now that these companies are going into what we'd call quantity production. A thousand turbines in a calendar year is quantity production. There are some companies which are at that stage. But first I want to show you a few slides of the turbines that you will be seeing in the films.

This is Fayette. They probably will put in 750 turbines this year, they put in 300 last year. The 10 meter machine, steel reinforced blades, only put out about 35% more than the best strip theory that we could come up with and we can't figure out why. Riso knows! The Danes are far ahead of us in the application of empirical lift and drag data to performance curves.



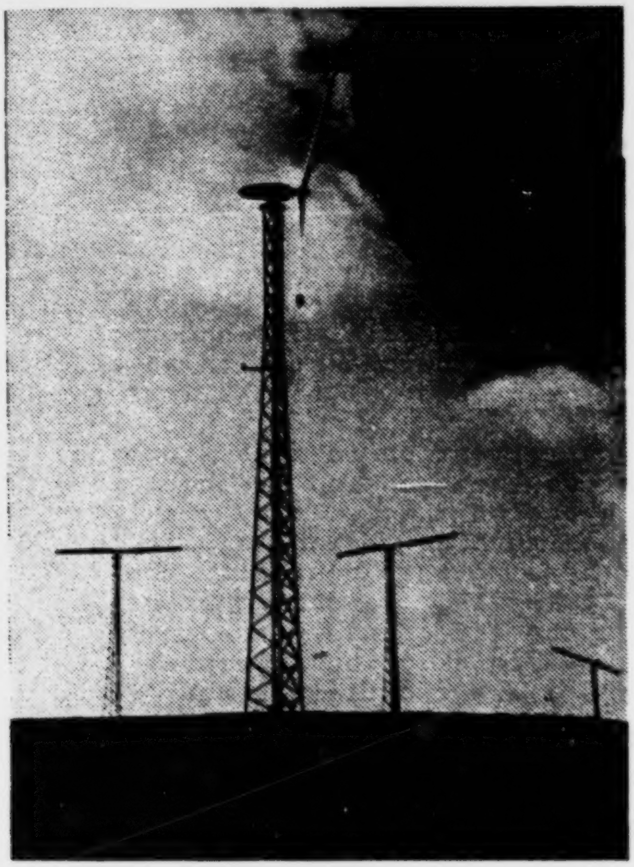
US Windpower which now has about 700 machines in arrays in the Altamont Pass, California, are the biggest. They will install another 500 to 800 machines this year and early next year. The biggest manufacturer in the U.S. wind turbine wind farm industry still has less than about 100 employees, assets probably less than about 5 million and probably debts that are a lot more than that.



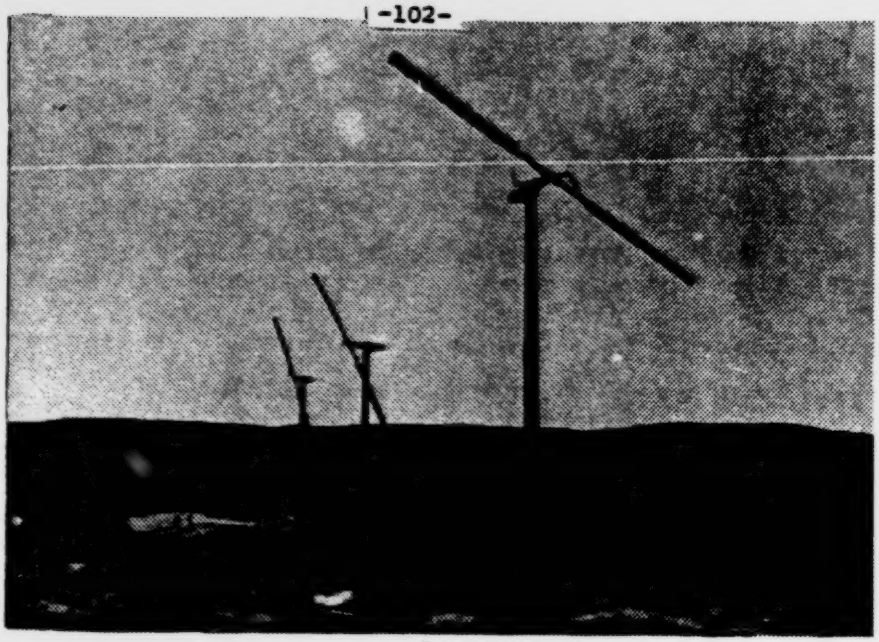
This is Wind Power Systems out of San Diego, California. A machine of roughly the same diameter as the Fayette, around 10 meters and rated around 55 kW.

This slide was taken at Tehacapi, California which is different site from the Altamont. The films are at the Altamont.

This is an ESI (Energy Sciences Inc.) machine. It is the first two-bladed teetering wind turbine rotor of any consequence lately and has worked out very fine, particularly due to their great investment in time and key personnel in research and development in the field. They have the best research group of any of the turbine companies, probably as good as Rocky Flats used to be. Now, many of the Rocky Flats people are at ESI.



This a Jay Carter 25 kW, 10 meter system. And it was originally designed for a onesy-twosy application at farms and ranches, etc. They did put out a number of those, but they are up in the hundreds production level of this machine for wind farms. They have a new machine just out that looks identical to this one only it's 200 kW. Same design features. This is another two-bladed machine.



The last machine that you will probably see is the Windtech machine. This is the commercial off-shoot of the UTRC flex-beam rotor. It's fiberglass, with an effective flapping hinge in the flex-beam material that allows the blades to flap.

I want to call your attention to these turbines that you will see. Bear in mind that you are looking at about the 4th or 5th design iteration on each one of them. In my view, you are looking at two philosophies of turbine design, all in the 50 to 100 kW size, because that is the size that best fits the tax shelter package in California. It is also the size that can be best produced in small quantity at the end of the year, in the last quarter, like Christmas cards. We think of ourselves as a Christmas card industry. But there are two classes that I would call your attention to: three-bladed class and two-bladed for want of a less obvious parameter.

The two-bladed machines offer blade flexibility or root-hinge flexibility to relieve blade root bending moments, which is a logical approach if you are using a two-bladed hub.

In the three-bladed approaches, some are flexible blades which allow the relief of some root bending moment. And some of them that don't are very stiff blades. Five out of the six leaders are fixed pitch machines. The operating range over which they operate as fixed pitched machines makes them vulnerable to the uncertainties in the lift and drag predictions. The other machine, the US Windpower machine, is variable pitch. Its' variable pitch, used to control power, has not been successful.

(FIRST MOVIE)

This is the Altamont Pass in California, about 40 miles east of San Francisco. These are the machines you will see when you drive through there. Here are the Fayette machines, right off the Interstate. They are 10 meter diameter, three-bladed, steel reinforced, with a fiberglass skin.

These are US Windpower machines. They started building their arrays on the ridge tops.

These are the ESI machines which, as you can see, are quite a bit different.

One thing you notice about the Fayette turbines is that they are experimenting with different rotational speeds, e.g. different rpm operation. They have decided on a generator which is an off-the-shelf wind turbine generator by Reliance that is a two speed machine. It allows them to maximize the power coefficient over a wider range. However, the electronics have not worked very well yet and you notice a lot of machines are stopped there. Those were the first 40 machines that Fayette put up a year ago where they had experienced very bad fatigue failures.

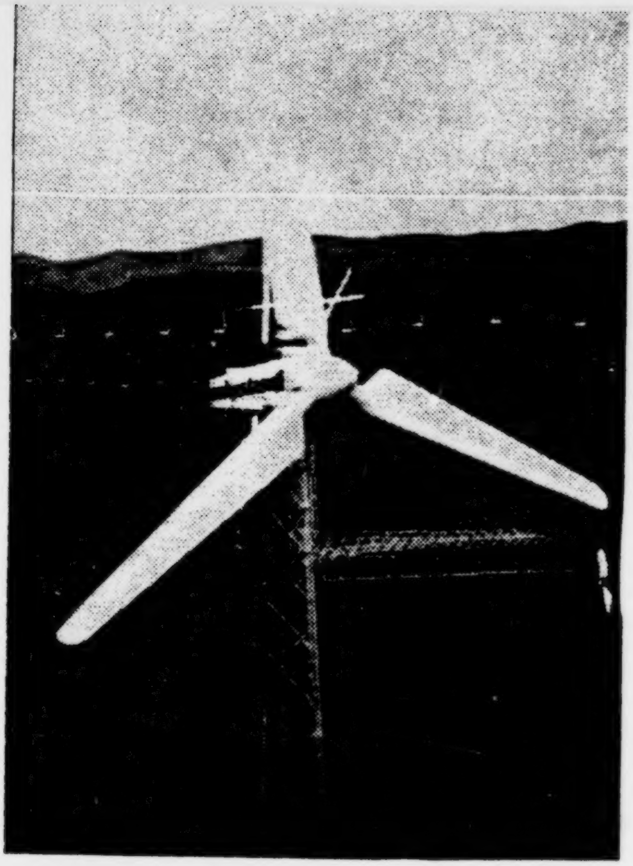
Those are two Vestas machines, for those of you who are quick. And there are a few ESI machines working there.

The Altamont Pass winds occur in the summer time and they are typically a night wind. At midnight the wind is often averaging 38 to 45 mph. The standard deviation at that point can be something less than eight mph. So it is very strong and steady from the West.

This is the first Fayette array. Some machines are operating and some are not.

This is a US Windpower array. Those are two Vestas machines. Those are Windpower machines operating in the background. The one thing that you can notice looking at those is that they are closely spaced in the orthogonal wind direction. As a result when the wind is quartering, they shut down every other machine. They have to do that because otherwise they get into a very severe yaw instability that is caused by wake effects.

(SLIDES)

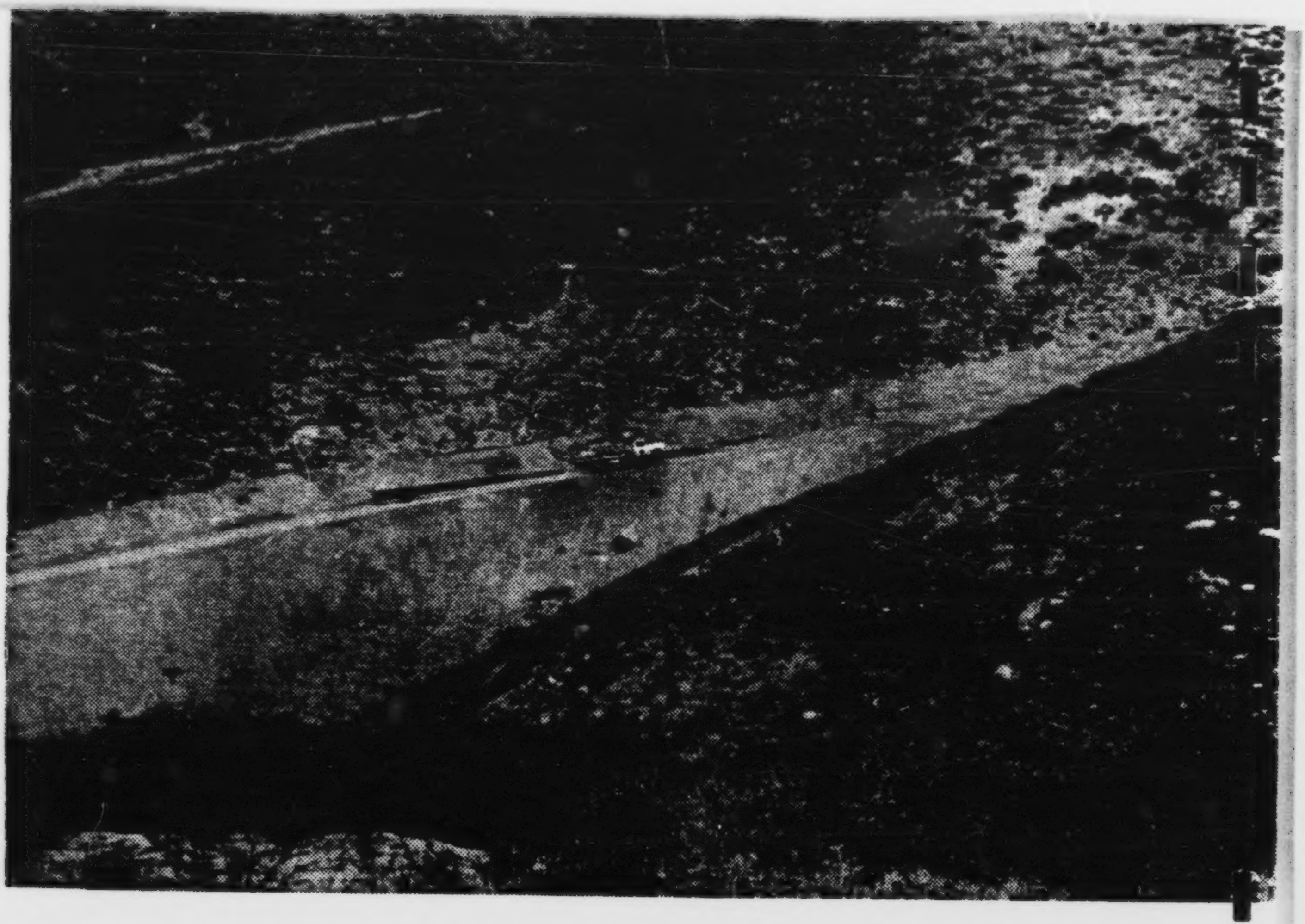


That's the Vestas machine. I bring it up as a footnote. This year the Danish machines are going to make very strong inroads in the wind farms. There are many, many of these machines that have been ordered for installation this year and next year as well. It is an interesting turn of events. The US Windpower turbines that preceded this slide are more aerospace quality. They are lighter in weight, higher performance, higher tip speed. Whereas the Danish machines we think of as diesels. They operate at low tip speeds, low rpms. They have a very boilerplate, heavy, what I would call a naval architecture approach to design. Hence they are more reliable. They are more expensive per kilowatt hour on paper but we will see how they live up to their claims in practice. These Vestas machines are doing very well at Tehacapi and also at the Altamont.

Let's examine the turbine cost for a wind farm where the typical installed price of a turbine is $100,000 to $150,000 each. Remember you are talking about a 10-15 meter diameter machine, a small machine. Out of that 100 grand or so around 40 to 50 grand goes into the turbine: that is the turbine manufacturing cost. About 10 grand of that is in the drive train and another 10 in the rotor with the rest in other hardware. Where does the rest of the money go? A lot of it goes to the brokers. We are being driven by tax shelters, and as a form of government subsidy the tax credits applied for last year and this year will be more than the NASA MOD-2 budget. In fact we are up in the couple of 100 million dollars of government subsidy via tax credits. And anywhere between 5 to 15% of the total brokerage will come off the top to the broker. Then out of what is left you have to do such tasks as building roads. US Windpower is an example, this is their first ridge top array a year and a half ago. They spent around $22,000 per turbine just on roads.

Again Altamont Pass. It is green only about three months of the year, then the rest of the year is real hot and dry.

Roads at Tehacapi. This is probably the easiest road at Tehacapi. That is a Wind Power Systems array. I show this slide to point out one other thing. These machines are also cubic close-packed and as a result, the performance of these machines is far lower than an independent single machine at a good wind site. Some of the manufacturers are trying to understand the wake effects, some are not. Nobody is talking about it.



This is a serious road at Tehacapi. It is at the Arbutus site. where there are around 80 Windtech machines going in this year. This is at a six thousand foot elevation. by the way.

The next thing is the sub-station. This is a very significant part of the cost. We think of the sub-station as being 5 to 10% of the total brokerage package. It can be far less or far greater than that depending on how clever you are at writing your interconnection contract with the utilities. At the Altamont Pass, PG&E buys all the power. At this point in time there are over a 100 MW of installed wind power capacity. And by about the end of January next year there will be around 250 MW installed capacity.

This is the Tesla sub-station where virtually all the power goes except for a few smaller ones.

The next one is inside contruction, the foundation and reinforcement. We have seen tower failures due to the wrong kind of reinforcement. We haven't seen any slope instability at the Altamont. That was probably the only civil engineering risk factor at all at the Altamont. It is a perfect site for wind turbines. There is no lightning. There are no high gusty winds like at Rocky Flats, or PEI, or at your typical Canadian sites. If you can't make it work there you might as well hang it up.

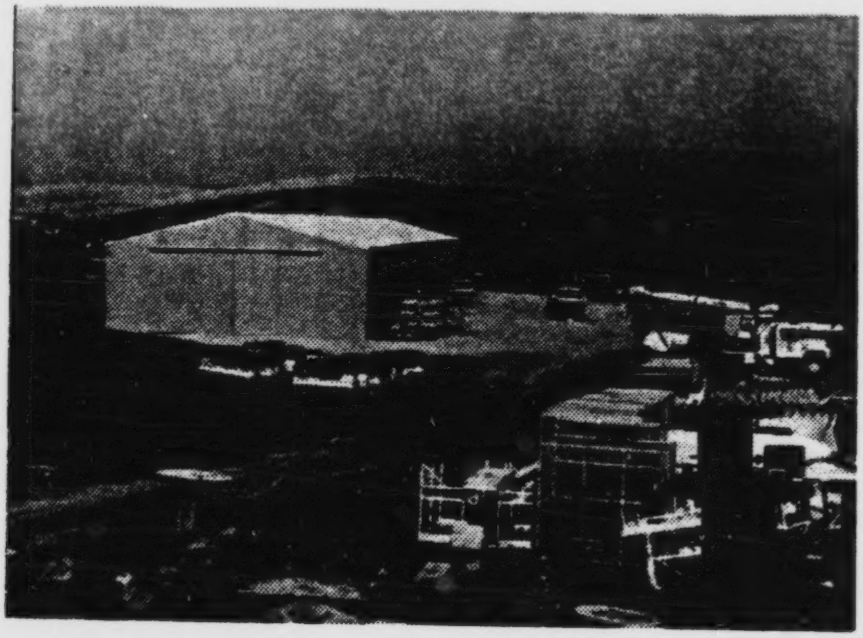
Drawing the cable and putting in the conduit: it can amount to $10,000 per turbine.

At this Tehacapi site there is a lot of rock and bedrock exposed. If the Electrical Code says it got to be in conduit 18 inches down, that is what you've got to do, Jack.

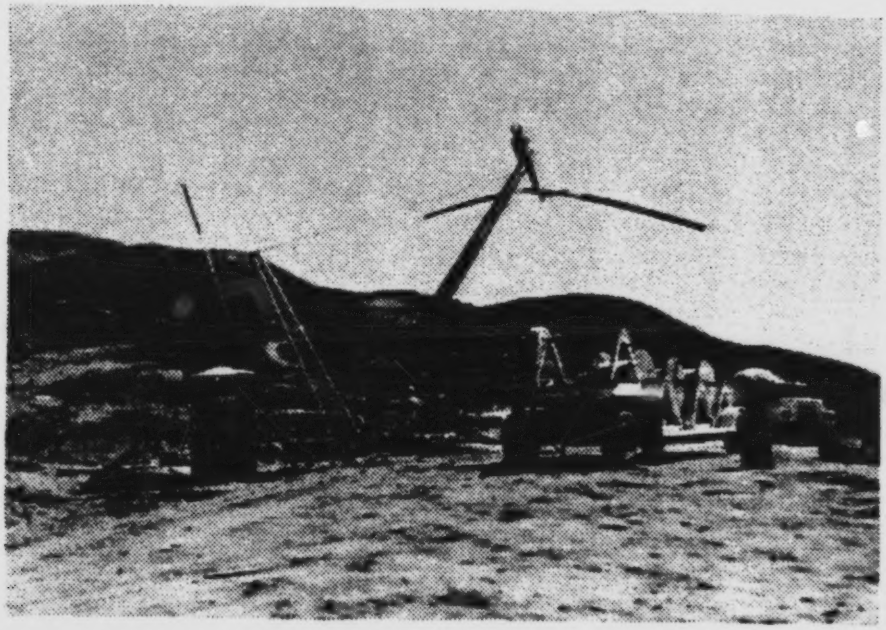
Then there are the control panels or test shed or control enclosure buildings. Luckily at the Altamont we aren't exposed to the heavy weather that you have. So we don't often have to put the control boxes inside the buildings like this. This is an ESI enclosure and it is very typical. The ESI array of 20 machines, each mounted with its individual control panel in the array.

[The meters that they are looking at are the two Vestas meters. At that point they happen to be running in the wrong direction. A little backwards there, because they had a little phase reversal, but that is common.]

The next one is the physical plant. These buildings were erected by Fayette to do the assembly at the site at their first wind farm. The buildings have since doubled in size. The number of turbines installed have also doubled in size. You add all that together and it comes to a pretty penny.



You erect the turbines in a normal way. Right now Jay Carter and Windtech have elected to stay with the gin-pole winch arrangement to erect their turbines, and also to lower them for servicing. But both have sometimes found that it is cheaper to have a crane or bucket truck at a windfarm site. Just recently, two weeks ago, Enertech installed its first 80, that is eighty, towers in two days using a helicopter. They are in the process of planting their 144 turbines on the towers now using the same helicopter, and it is working out real well. So there are some economies of scale that we are just beginning to learn about in installation.



(FILM)

Some of these turbines that you see are reaching some sort of maturity level. On a scale from one to ten of comparing them to a refrigerator, I'd put them down around a one and a half on the maturity level. These turbines are the result of a manufacturing and installation process which is at the moment dependent on the tax credit. As a result the greatest expertise that you'll find in these machines is financial expertise. While we are beginning to get some installation expertise, there is precious little engineering expertise. There is virtually no product engineering or product development in the Detroit sense.

One bright spot is a new Fayette drive train this year which is handled entirely by Reliance Electric as a sub-contractor. Reliance builds the whole bed plate with the yaw mounting gearbox, couplings, main shaft and two-speed generator as a unit for Fayette, all checked out in the factory beforehand. So Fayette does not have to fuss around with alignment of shafts. This is a wind power, off-the-shelf line that they are beginning to carry. Reliance is supplying other manufacturers as well. But that is a very bright spot. If anybody should and could do product engineering on the drive trains it is Reliance. We should keep out of it.

Fayette has about 100 employees and maybe six or seven are engineers, usually aeronautical or electronic. That is another sore point. We all thought in the very begining that microprocessors were going to be the answer to these turbines. I am a bit pessimistic about anyone who blithely says that the "microprocessor controlled" vertical axis or horizontal axis machine is preferable. The ultimate wind machine control is an on-off switch. ON! ... OFF! I haven't seen a microprocessor yet that is reliable in the field. On the bench they work fine. As a result this year Fayette, GE-3 and Windtech have gone right to the boss, right to Eaton/Cutler-Hammer. They are spending 2 to 3 grand per turbine on a bullet proof microprocessor system that was invented for assembly lines in Detroit and monitoring of nuclear power stations. Eaton's not missing the boat.....

If you have any questions just fire away.

Q. Do you think American manufacturers should change and be more like the Danes and focus more on energy production instead of tax credits?

A. Of course, of course. We have around 1200 turbines, around 100 MW of installed capacity this year in the Altamont Pass and yet we produced only 29 million kWh. Now that power comes out to be around $2,000,000 at avoided cost from PG&E. But when it costs you 2.5 million dollars just to operate and maintain those guys, your net is down to zero, less than zero. Nobody is publishing or talking about what they are putting out per turbine, except Farrell Seiler (Wind Energy Report) whose dividing the numbers that he finds in interviews. Well, the averages are pretty low. If you take the next very painful step and compare the average turbine production in kilowatt hours to what was predicted in the offering memorandum then you get a rude shock. The typical production was estimated as 200,000 kW-h/year out of a 50 foot diameter machine in the Altamont, which includes assuming 98% availability, maybe an hour a week of downtime, winds like we had in the last five years in the Altamont etc. etc. But the actual fact is, they are averaging around 40,000 kW-h/year. They can always find a way to weasel out of it by saying 'well we didn't do it because the winds were low this year'. Now 40 over 200 is something, you know, it is not zero. Some are zero. In fact some of them didn't have blades. The IRS is beginning to listen and walk around. And you see these guys in three piece suits in the Altamont and you know that they don't work down in the dusty trenches. Especially, if they carry brief cases and have a hard jaw.

(FILM)

The US Windpower machines: you'll notice the intermediate machine is shut down. Well, that is a very wise thing to do. They have a pitch control that allows a number of intermediate pitch angles.

Two Vestas machines, they just sit there like diesels, all day long, just going and going. They are quiet because they have a very low tip speed.

The US Windpower machines tend to yaw fairly fast. They are real interesting to watch, particularly in a high wind. That is another US Windpower array..........

recording tapes changed

Looking towards Tracy in the big, hot interior valley that drives this big heat engine that causes the Altamont winds. That part is full of Palenkos at the moment, for those of you who are familiar with that Dutch machine. Just beyond that are the Enertech 40's going in.

There is an ESI array right there. There's some US Windpower movement. Windpower started off with no yaw restraint, a completely free downwind system with a very high activity factor rotor, as we call it. They had such yaw excursions both in magnitude and direction, that they were getting some blade tower interaction, which is fun to watch.

There is an ESI machine stopping. The ESI machine depends on a brake to hold it in position and also to stop it. There comes Farrell Seiler in his helicopter, getting some aerial photos. US Windpower has gone to a yaw restraint system which is really a yaw damper. There is an ESI machine speeding up. They motor the machine slightly to energize the field and avoid current peaks.

There is a Windpower machine slowing down by going into feather. You see it happens rather quickly. Of course being an aerodynamicist, I believe in pitch control.

My preferred rotor would be one that feathers when it gets hit with an overload. Whether the overload is caused by ice or strong gust or a hurricane or the grid falling off and the machine over-speeding. I'd like to see it feather and just sit there, like dropping the sheet on a mainsail or a jib if you're sailing. That's what a windmill wants to do. Anyway, that's where I am.

Five out of these six manufacturers like fixed pitch machines. Now the Danes are a good proponent of that. Their machines are almost all fixed pitch. The thing is when these blades go into a stall they keep producing. They go into stall deeper, they still keep producing and the air loads become very low. Like I said we are 25% off with the calculations - that is the best we have done.

This is Tehacapi again, Wind Power Systems. They started off with a hand-layup, fibreglass blade. They had some blade root failures, because they were running up to 10 or 15 thousand micro-strain at the root. These blades cone back about 45 degrees just like the Carter machine. In fact these two are the most flexible FRP blades that are out there. With those kinds of fatigue-producing tip deflections - in gust events and load events, you can expect low cycle fatigue from practically any material, particularly fiberglass - at least that is my opinion.

This is the ESI tip brake, they wisely thought that they needed an aerodynamic backup to their mechanical brake. But there have been occasions when their triply redundant mechanical brake and the tip brakes have failed. Gougeon Bros., Inc. makes these very fine laminated wood blades. They are expensive, but those blades come out of the factory balanced to within an ounce. That's not just the first moment balance but frequency balance, as well. That's some quality control. I don't know how Gougeon does it, but to their credit none of these blades have broken in service. Some have broken when the tower sat down, and they have lost a few bolts down at the root, but none of them have failed under load.

Yaw instability is an aerodynamic wake effect that we thought we had a real handle on from helicopter and autogyro experience. Jay Carter has a fairly low thrust offset from the yaw axis of his machine's downwind two-bladed high activity factor - FRP rotor; very high coning, high bending in these blades - extremely flexible. In gusty wind areas, like Livingston, Montana, you will find that these downwind machines, once they get around upwind, will operate very nicely upwind. The only trouble is it reduces your tower's clearance. Jay got into that trouble, so he wisely added an empennage. He added it in the rotating system so that it became a duct which I think is rather cute! But how would you like to retrofit 2000 machines with those - not me. He still doesn't have a yaw drive on the 25 kW machine. I believe he has added a yaw damper like US Windpower has.

You can see a trend here. Ed Salter of Wind Power Systems, at first was building his own bed plates, then putting on one manufacturer's gearbox, it was a parallel shaft gearbox, and an induction generator/motor. Now, he buys them as a unit. that total blue unit comes directly from the factory, all he has to do is put his rotor on it and stick it on the tower and bring the wires down. If there's anybody that should be doing drive trains it is certainly not us rotor-people. It's got to be the Reliance's and the GE's of this world.

Fayette also started with a drive-train that they built up themselves. One difference that Fayette has in these factory ordered drive-trains, is that they have a separate wind shaft. That is, a large shaft mounted in big pillow blocks that takes all the bending loads of the rotor and isolates the gearbox. They have fairly good gearbox life as a result of that. The other problem is that they are putting out 125 kW in a 10 m machine. So when you put a 150 hp gearbox in there, you can expect to find a little wear. They had to upgrade everything. Again, the theory failed to predict the power that those machines would put out. They operated far into stall.

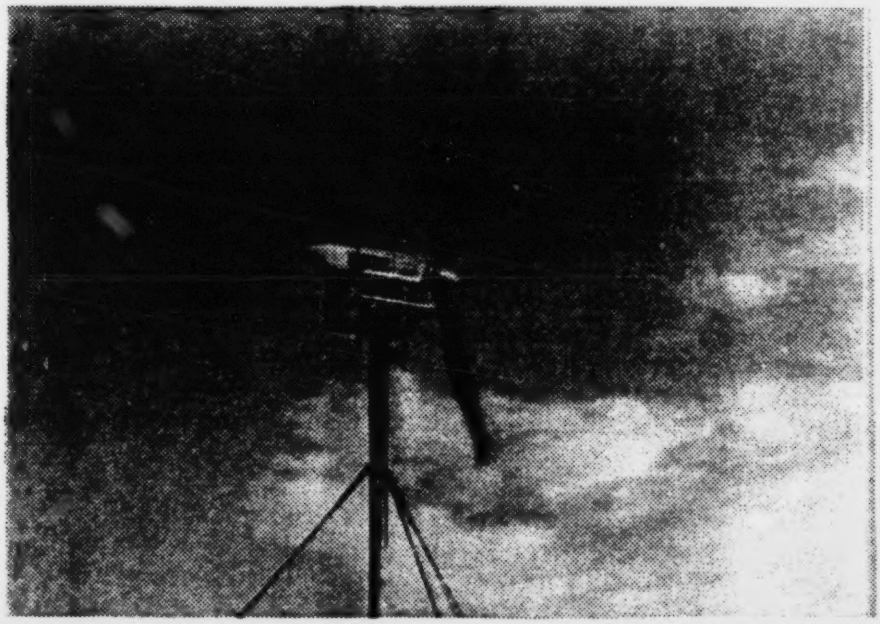
Here is a good view of the US Windpower spacing. Just to give you an idea, the Altamont Pass is in about its 25th month of development, serious windfarm development. There are around 36 square miles available, of mostly good wind land. It all looks like this with these rolling hills. Some of it is flatter than most - like this part here. But that's gotten all snapped up. At the end of this year, there will be about 18 square miles developed. So at the end of this year we are going to be about half done in the Altamont. So the company that has to build 500 machines this year, 1000 machines next year and 2000 the year after just to stay in business to cover it's losses from the year before, has got to find another place to put those 2000 machines. So start looking for good windy places if you want American machines. Maybe you can do better, I hope that you try.

Now, here is a sequence - and this brings me to the end. This is US Windpower's first machine. It was a fixed pitch machine, three-bladed downwind because it was a derivative of the University of Massachusetts machine that we built. This is a little bigger. This is about 40 feet in diameter. The UMass wind Furnace was 32 feet in diameter and used fiberglass blades. It did not work real well, but it sure gave us a lot of fun.

This is US Windpower's second machine. They went to a shaft mount reducer, and put the wind shaft right on the main bearing of the shaft mount reducer, which the manufacturer swore up and down would work, gave a fourteen year warranty and said, 'Oh, that's fine'. When they started to wear out after about 18 hours of operation, the manufacturer said, 'Well, there is something that you did not tell us. These things have higher loads than what you told us,' and they do!.

This was taken at Crotched Mountain in New Hampshire which was their first wind farm. There is nothing there now except blueberry bushes. In fact, I've been told the towers and the machines have been taken down and out to California in order to satisfy a little question about the longevity of those tax credits.

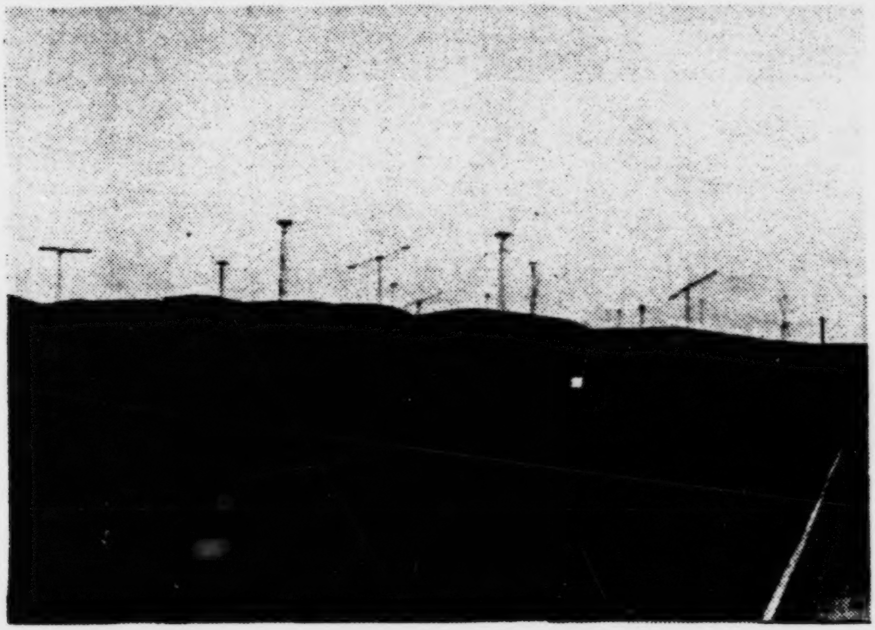
This is their current machine. US Windpower has probably the best physical plant of anybody. They don't do any tower climbing at all. You see a little platform up there, that's just for OSHA. In fact, all it is used for is when they install the machine, a guy goes up there and plugs in the power cords and comes down. When they want to work on a machine they bring in a crane and a special truck out there, one behind the other. They just lift it off the tower, put it on the truck, take off the blades and go right over to their assembly building. They don't do any work in the field. Fayette is just the opposite. Fayette does all its work in the field, as you could see from the work platforms.



You notice the work platform on the Fayette machine. It was not done because OSHA required it - it was done because the guy who designed the machine in the first place is a heavy equipment designer and he wanted a solid place to stand and work and have his lunch.

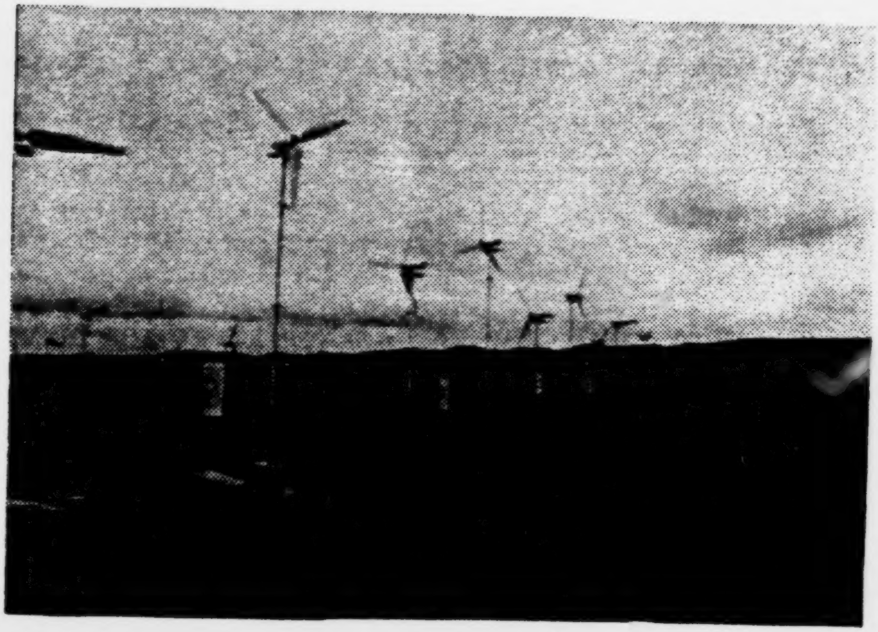
Again, you can see the different rpms the different machines are operating at. This machine again is a 10 m rotor, fixed pitch. Tips are centrifugally actuated into stall in the event of overspeed. That system works pretty well. It is nothing more than the Danish system that has been used for about 20 years and probably a Soviet system many years before that. You can see the tips feathered on the ground there prior to being installed. Those were the machines that had the fatigue failures.

There's the Vestas just cranking away. The nice thing about the Vestas is its great visibility - big wide white blades - and you can see them from all over the Altamont. So most anywhere you stand you can look down and see if there is wind at the Vestas site. Of course it doesn't take much to get them going either.



There is an ESI machine. We notice one thing, looking at an ESI array: if you watch it for any length of time, those two-bladed machines will synchronize so that the rows downwind will find the blade in the same azimuth position after a good long time. It looks like a whole bunch of soldiers marching, although they may start off in random step.

Fayette Array



Here is a US Windpower array again. At this point in time, I think there are, out of 700 and some US Windpower machines installed, a little over 100 that are operational. The rest of them have had one failure of a kind or another and have been shut down since this is the off wind season out there. It is also the off maintenance season for US Windpower because they reduced their maintenance staff to very little to try and weather the storm here.

Here is a US Windpower machine in a start-up pitch angle and there it is a few seconds later in the run angle. It is a very high activity factor rotor. That is, one that has large twist and taper and a high lift airfoil - it will go - it will zoom! When you put that rotor in flat pitch you better watch it and you better be ready to energize a field or you probably have lost it.

That's the end of it. I'd be happy to answer questions - I wish I had a more upbeat presentation saying things were all going well, but they aren't.

Q. Is it possible that companies that might be viable will be dragged down by those which are not?

A. It's not likely because the financial community is running our industry, at least in my opinion. I would hope that more companies take ESI's direction. ESI spent a lot of money this year in trying to solve some sophisticated aerodynamic and structural dynamic problems that they encountered which were causing imminent failures in the field. To their credit they caught the failures before they had very many rotors on the ground. They hired the two best people - UMass graduates - to head up a team. They also got Craig Hansen from Rocky Flats. They must have a half million dollars in just research and development equipment, such as nine-track tape recorders. They have something that looks like what Malcolm Lodge has got. We all wish we had a facility like Malcolm's. We all wish we could do that sort of data collection and reduction that he does just as a standard procedure but we can't. We are using mechanical strain gauge recorder's developed in the 20's for ships, because we engineers in the field are the poor sisters. We get whatever few pennies are left after everyone else has their cut. But I think that with the quantity of machines going out this year and the amount that these manufacturers have been burned by failures and retrofits, they are beginning to wise up. Understand that you have to go a little more slowly, you have to have some damned good people who are fast on their feet in the field to fix these things and who understand the problems that cause them.

Q. What is the most common failure?

A. Blade root failures: one kind of fatigue or another, low cycle fatigue in FRP composities, simple over stress in machines of little experience. We found fatigue part way out on the blade with twisted, tapered shell, D-spar shell combination. The highest stress does not occur at the root, usually it occurs about half-span and at the trailing edge because that's where the extreme fibres are farthest from the neutral axis. We look for cracks and delaminations at that point. It is hard to generalize beyond that. I would say that if somebody had a choice of where to put development money, I would put it right in the rotor. I wouldn't give the drive train, or the tower, foundations or even a controller a second thought - put it right in the rotor.

Q. Are not those operating at one quarter capacity losing their shirts?

A. We have a vacuum of information. None of these operators wants to let out his production figures. None of them wants to let out what his maintenance problems are. None of them want to let out what his retrofit costs were last year. They don't want to let out anything, except the glorious good news. Now, the operators, the windfarm developers are just beginning to publish their output figures. If you put two and two together, like go out there and count the machines that are operating, divide that into the monthly production then you can get some idea of what they are doing. There are bright spots. There are single US Windpower machines that are producing very close to their prediction. And the same it true of Fayette. ESI, I would say has the highest average closeness to their predictions but it is largely because they were conservative in their predictions. Now, if you are a new developer with a new machine or a new version, and you have got a conservative output prediction, you are not going to sell it out on the street against these other guys who are claiming they're going to make the moon. So we are in a vacuum of information. But it is beginning to come out now.

Q. Would you make an estimate of output reduction due to wake effects?

A. Well I can make a stab at it. I don't have any quantitative numbers that I would trust. We have taken segments of an array and taken power data and then shut down adjacent machines, upwind rows and downwind rows and so on and tried it. We find as much as a 25% difference. But in other cases when we shut down machines we get a loss. So it is something I find difficult to generalize about. One of the big problems in an array is where and how do you measure the free stream wind velocity. The only proper way is to put anemometers all around the array. We never have enough resources to that. So we are left with trying to do correlations with bow wind speed, that is, the wind in the upstream of the turbine wake, to what the free wind was on an isolated turbine that we tested some months earlier. So the science in the field data interpretation has a ways to go as well. Now, ESI has done an extremely good job at this but they are not giving out any details.

Q. What is the motivation for putting them so close together?

A. Well, it reduces all those costs, the road, the conduit, and all the rest of it. Plus, you may only be able to set up one land owner and he has only got two thousand acres - that's what you've got to deal with.

Q. Do you know anything about the Windworker Ten?

A. Some: the Windworker 10 is a 10 metre, three-bladed machine that was designed by Windworks... I have not seen them in windfarms. There is a proposal to build over a thousand of them in a windfarm, and hook them up to big Geminis, not little ones. I think that rotor has a very great potential for low root bending loads because of its flapping hinge. But the present machine looks over-complicated to me. I think it needs some production engineering. I think it needs someone from Detroit. You know how many production engineers are out of work in Detroit?

Q. Do you have any comments about the general direction of development of the industry in the United States?

A. We in the United States industry may have started off with too aerospace an approach. We may have been talked into it by DOE, but it is too easy to point the finger at them because we were around before they were, too. So, we may have started off with trying to make them too much like C-5A's or F-16's. Whereas the Danes just went along, they didn't know all the computer stuff we knew but they didn't need it.

Q. How do you synchronize all those turbines with the utility grid?

A. They are virtually all induction generators. They all virtually go into a single point for each array, or each segment of an array. If you have 700 turbines, then you must have 10 or 12 segments that go into collection points. There are usually three transformer points. There is one where it comes down from 69 kV into a distribution voltage which has to go 3 to 10 miles typically. And that may be 12 kV or 6.9 kV. And finally there is the pad transformer, which will run only three or four machines, at most, ten. US Windpower may run ten. So, it is like a tree branch. We have never seen a synchronizing problem. We have seen power factor problems; we have seen cables over-heating because of too much current; we see in one part of an array that you may have a horrible power factor, and a horrible output, where at the same time, in another part of the array, it is doing wonderfully. You try to trace it down to the distribution boxes, or the controllers, and not being that, it has got to be in the wind somewhere. So, there is a lot we have to learn about that. Now, for your information, at this point PG&E is just beginning to get upset about power factor. Or, let us put it this way. They are not getting upset, they are beginning to say: "Well, I think you guys ought to be measuring power factor'.

Application of Large Wind Turbine Generators in Utility Networks

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"APPLICATION OF LARGE WIND TURBINE GENERATORS IN UTILITY NETWORKS"

ABSTRACT

The development and potential of large wind turbine generators (WTGs) and alternative methods for their integration into utility networks are reviewed.

A cost and economic comparison between wind turbine generators and conventional generating plant is presented and conclusions are drawn concerning the future role of wind power in meeting energy needs.

INTRODUCTION

Sources of energy can be grouped into two categories. These are non-renewable, such as coal, natural gas, oil and nuclear, and renewable, such as wind, solar, hydro, geothermal and biomass.

The utilization of these sources during the last hundred years shows the following trends:

BEFORE 1880.............. USE OF FOREST PRODUCTS AND COAL

FROM 1880 TO 1920 .... SUBSTITUTION OF HYDRO-ELECTRICITY AND NATURAL GAS FOR COAL

SINCE 1920................ USE OF OIL

SINCE 1960................ INTRODUCTION OF NUCLEAR PLANTS

SINCE 1975................ SEARCH FOR ALTERNATIVES FOR OIL AND ALL OTHER NON-RENEWABLE AND IMPORTED ENERGY FORMS

The development of wind energy conversion systems during the last decade indicates that this form of energy could play an important role in the future.

In order to utilize wind power, a means of converting energy in the wind into a more acceptable form of energy is required. A wind energy conversion system can be based on any physical configuration which develops an asymmetric force when placed in a wind stream. This force can be arranged to produce rotational, translational or oscillating movement and mechanical power extracted. This mechanical power can be used directly or converted into other energy forms such as electrical energy.

The most highly developed wind energy conversion systems convert wind energy first into rotational mechanical energy and then into electrical energy. Such a conversion system is called a wind turbine generator (WTG) and it is the application of such machines into utility networks that is the subject of this paper.

Figure 1 compares the development status of the more advanced sources of renewable energy and indicates that wind power is the only source which currently has commercially available production units.

WIND POWER POTENTIAL

Initial estimates of the potential of the wind power resource in Canada are summarized in Figure 2. The results represent the exploitable annual average electrical output assuming that wind turbine generators are installed within 150 km of existing electrical transmission lines and that they are spaced the stated number of diameters apart.

The wind power potential from Figure 2 is compared with 1978 existing generation in Table 1. The significance of the wind power resource potential is clearly shown by Table 1. (1)

Figure 3 shows the wind resource potential at the La Fonderie site of the Project Eole, 4 MW, vertical axis WTG. This indicates the site to have a wind energy capability of 200 to 300 W/m^2 whereas detailed site measurements show the actual energy capability to be approximately 400 W/m^2.

The implication is that macro-scale wind assessments appear to underestimate the resource. Exploitable sites may exist in areas currently considered unsuitable for wind power development.

WIND TURBINE GENERATORS

Wind turbines are classified in terms of the orientation of their axis of rotation in relation to the wind stream. The two principal types, vertical (VAWTG) and horizontal (HAWTG), are illustrated in Figure 4.

The development of horizontal-axis wind turbine generators (HAWTGs) is shown in Figure 5 and that of vertical-axis wind turbine generators (VAWTGs) is shown in Figure 6.

The relative development status of the two types is that both the MOD-5A, 7.3 MW HAWTG, and Eole, 4 MW VAWTG, are at the design stage.

The principal differences between the two types are:

(i) The power train components for the HAWTG are in the nacelle at hub height whereas they are at ground level in the VAWTG.

(ii) The HAWTG rotor and nacelle must be aligned with the wind direction whereas the VAWTG is not sensitive to wind direction.

(iii) The HAWTG normally uses blade pitch control whereas the VAWTG has fixed blade pitch.

The more important attributes required in a wind turbine generator, which is to operate in a utility network, are listed in Table 2. The two types under consideration are both capable of meeting these requirements.

NETWORK INTEGRATION OF WIND POWER

The various operating modes which may be used for wind turbine generators to contribute power to a utility network are illustrated by Figure 7.

The fuel saving mode involves the WTGs supplying the maximum possible power into the network as determined by the wind speed. The power contribution of the conventional plants is then reduced by an amount equal to the WTG contribution. The practical limitation to this is that power produced by must-run generation cannot be displaced by the WTGs and would therefore require some of the WTGs to be shutdown under high wind speed conditions. Such an eventuality would reduce the WTG plant factor and increase the cost of energy produced by the WTGs.

To avoid "dumping" wind power, any power, surplus to network load requirements, could be diverted to an energy storage system for use when the demand increases.

If the network includes hydro generation, the energy storage system may take the form of reservoir storage of any water not used by the hydro units due to operation of the WTGs. The system would be most effective if additional hydro units could be put into service for peaking duty. This is the hydroelectric supplement mode in Figure 7.

The hydroelectric supplement mode may be taken a step further to the pumped hydroelectric mode where the excess WTG power is used to pump water up to the reservoir for use at load demand peaks.

The proposed use of hydroelectric storage is a means of reducing the cost of energy storage by making the best use of existing facilities if they are available. Other forms of storage have been proposed and evaluated as summarized in Table 3.

It should be noted that the economics of energy storage is becoming attractive to utilities even when renewable energy sources are not considered. This is because low cost energy stored for use during high demand periods is becoming competitive with high cost energy from low cost peaking generation units.

In summary, there are three basic network integration scenarios for WTGs and these are:

(i) The total WTG capacity in relation to the conventional generating capacity (penetration level) is low so that no attempt will be made by the WTGs to displace must-run generation.

The cost of WTG-produced energy must therefore be competitive with the cost of energy from units required above the must-run level.

(ii) The total WTG capacity represents a high penetration level but no energy storage is included.

In this scenario the WTG utilization is reduced and hence the cost of energy is increased. It is in this scenario that the breakeven WTG capacity (maximum penetration level) is likely to be found.

(iii) The operating economics of the network, with conventional generation only, is such that it is advantageous to install energy storage facilities for peaking purposes. In this scenario, the lowest cost energy for storage would be used and so the WTG energy must be competitive with the lowest cost conventional generation energy.

The second scenario, (ii) above, is impossible to generalize since the problem is specific to a particular network. The first and last scenarios, (i) and (iii) above, however allow all the energy produced by the WTGs to be absorbed either directly or indirectly by the network. In this case, a simple comparison between the busbar cost of energy for WTGs and all conventional forms of generation is valid.

This assumption is made in the following economic evaluation.

COST AND ECONOMIC CONSIDERATIONS

In the evaluation of a new product, it is normal practice to estimate the cost based on four production scenarios.

These are:

1. Prototype;
2. Second unit;
3. Limited production;
4. Mass production.

Approval for a demonstration project and for commercialization of the product are based on its technical and economic viability; the latter being based on the mass production scenario if the marketing potential justifies it. With wind power, hundreds of machines are required for a generating capacity equivalent to a conventional power station and so mass production is a necessity.

Table 4 shows the mass production (100th unit) cost breakdown for the MOD-2, 2.5 MW HAWTG.

Table 5 illustrates the procedure for calculating the cost of energy produced by the MOD-2 HAWTG.

Since the power in the wind is proportional to the cube of wind speed it may be expected that the site of the WTG and its wind regime can have a significant effect on the cost of energy. This is confirmed by Figure 8, which also shows indirectly the scale of difference between second unit and mass production HAWTG cost.

Figure 9 gives comparable cost and economic data for the VAWTG and additionally indicates that the energy payback for VAWTGs is between 6 and 24 months dependent on the site wind regime.

A further economic benefit from the establishment of a wind turbine industry would be the creation of jobs. As shown in Figure 9, a minimum of 16,000 direct jobs would be created with a production rate of 20 units per month.

Table 6 summarizes the capital cost of various types of conventional generating plant and includes WTG costs for comparison. The capital cost of conventional plant is shown to have increased sharply in the past decade.

Table 7 indicates the cost of energy produced by a 6.6 MW VAWTG in relation to the cost of energy produced by oil-fired plants as affected by rising oil prices (2). Larger WTGs are capable of reducing the cost of energy further.

The results indicate that WTGs are potentially capable of competing with conventional forms of generation.

A disadvantage of WTGs, which is often cited, is that they occupy a large land area. To put this into perspective, take a nuclear generating station as an example.

A wind energy farm with large WTGs installed in a wind regime of 7.15 m/s (16 mph) would occupy an area of about two or eight times the land requirements of an equivalent nuclear power station including the controlled area. The factor of two assumes only the total land area of all the individual WTG sites whereas the factor of eight also includes the land between the individual WTG sites based on a separation of ten WTG rotor diameters.

To date, the sceptics on wind farms have always used small 50 to 200 kW WTGs to make a point against the use of wind energy on the basis of land requirements.

CONCLUSIONS

The conversion of wind energy into electrical energy, safely and reliably, is currently feasible. The availability of the energy on a seasonal basis is generally compatible with the load demand in Canada so that supplying it through the utility networks is the most effective way to serve all sectors of the economy and achieve maximum national impact.

The potential of wind power in Canada is enormous and consequently, to take advantage of its potential benefits, its implementation must be made on a massive scale. This will automatically ensure a WTG mass production scenario and guarantee economic competitiveness with other methods of generation.

Such a large scale WTG application would also ensure that:

(i) Future Canadian energy needs will be met and export of electrical power to the U.S.A. on a large scale is conceivable.

(ii) Imports of non-renewable resources will be reduced.

(iii) The balance of payments will improve.

(iv) Jobs will be created.

(v) Environmental pollution will be limited.

The economics of wind power improves as the size of the WTG increases. It is imperative therefore that Canada's research and development efforts in the field of large WTGs should be increased and accelerated and the early commercialization of WTGs should be encouraged.

REFERENCES

1. Quraeshi S. "Large Wind Turbine Generators (WTGs) for Electrical Utility Application" technical paper for 11th World Energy Conference, September 1980, Munich, Germany.

2. Quraeshi S. and Richards B. "Wind Power - A Viable Energy Option", Energex'82 Conference, August 1982, Regina, Sask., Canada.

TABLE 1
INSTALLED GENERATION CAPACITY VERSUS WIND POWER POTENTIAL IN CANADA

REGION	TOTAL AREA Km^2	TOTAL POPULATION (APR 1978)	INSTALLED GENERATING CAPACITY, (MW) IN YEAR 1978				WIND POWER POTENTIAL @ 10 DIA. SPACING (MW)
			HYDRO	NUCLEAR	THERMAL	TOTAL	
YUKON	482 515	21 600	58	–	43	101	–
N.W.T.	3 379 684	43 200	47	–	118	165	31 500
B.C.	948 596	2 562 000	7 828	–	1 741	9 567	–
ALBERTA	661 185	1 998 800	716	–	4 460	5 176	48 000
SASK.	651 900	954 000	567	–	1 243	1 810	90 000
MAN.	650 087	1 030 000	3 178	–	489	3 667	108 830
ONT.	1 068 582	8 493 300	7 084	5 600	13 027	25 711	87 500
QUEBEC	1 540 680	6 298 100	15 480	266	894	16 640	108 000
N.B.	73 436	700 200	680	–	1 682	2 362	9 000
N.S.	55 491	846 700	360	–	1 370	1 730	11 700
P.E.I.	5 657	122 500	–	–	119	119	1 800
NFLD.	404 517	572 900	6 376	–	595	6 971	75 600
CANADA	9.922 330	23 644 800	42 374	5 866	25 781	74 021	546 730

TABLE 2
DESIRABLE WTG FEATURES - UTILITY VIEWPOINT

- THERE SHOULD BE NO CONSTRAINTS ON THE MAXIMUM WIND TURBINE GENERATOR (WTG) RATING IN A PARTICULAR APPLICATION OTHER THAN THOSE WHICH APPLY TO CONVENTIONAL FORMS OF GENERATION. BY IMPLICATION, IT SHOULD BE POSSIBLE TO USE THE WTG IN ANY CONCEIVABLE APPLICATION.

- OPERATION OF THE WTG SHOULD NOT DETRIMENTALLY AFFECT THE ASSOCIATED ELECTRICAL NETWORK WITH RESPECT TO SYSTEM OPERATION AND STABILITY.

- IN THE EVENT OF A RAPID LOSS OF WINDPOWER, SUFFICIENT TIME SHOULD BE ALLOWED TO START UP AND CONNECT ALTERNATIVE CONVENTIONAL GENERATION SUCH AS DIESEL, GAS TURBINE OR HYDRO SETS. THIS IS TO MINIMIZE SPINNING RESERVE REQUIREMENTS.

- FULLY AUTOMATIC CONTROL OF THE WTG IS ESSENTIAL.

- A HIGH RELIABILITY IS ESSENTIAL TO ENSURE MAXIMUM AVAILABILITY.

- THE WTG SHOULD BE EASY TO MAINTAIN BUT REQUIRE A MINIMUM OF MAINTENANCE.

- THE REQUIRED USEFUL LIFE SHOULD BE NOT LESS THAN 30 YEARS. REPLACEMENT OF PARTS WITHIN THIS PERIOD UNDER SCHEDULED MAINTENANCE PROCEDURES IS ACCEPTABLE.

- THE COST OF ENERGY PRODUCED BY THE WTG MUST BE COMPETITIVE WITH THE COST OF ENERGY PRODUCED BY ALTERNATIVE CONVENTIONAL GENERATING SETS.

TABLE 3
EVALUATION OF STORAGE TECHNOLOGIES

TYPE / ITEM	BATTERIES	HYDROGEN STORAGE	THERMAL	FLYWHEELS	ELECTRO-MAGNETIC	PUMPED HYDRO	COMPRESSED AIR STORAGE
MINIMUM ECONOMIC SIZES FOR UTILITY APPLICATION	10 MWh	10 MWh	600 MWh	10 MWh	10,000 MWh	10,000 MWh	100 MWh
ESTIMATED CAPITAL COSTS, $/kW (RATED) (IN 1975 US $)	180	300	100 - 400	400	500 - 600	200 - 300	230
EXPECTED LIFE, YEARS	10 - 20	30	20	30	30	50	20
DISPERSED STORAGE CAPABILITY	Yes	Yes	Yes	Yes	No	No	No
TURNAROUND EFFICIENCY, PERCENT	70 - 80	40 - 60	High	80	90 - 95	70	45

SOURCE: WIND MACHINES N.S.F. REPORT, U.S.A., OCTOBER 1975

BASIS OF EVALUATION

- STORAGE CAPACITY: 10 HOURS
- TECHNOLOGY STATUS: PRIOR TO 1975

TABLE 4

COST SUMMARY : 100TH. PRODUCTION UNIT, 1977 DOLLARS

TURNKEY ACCOUNT		COST
1.0	SITE PREPARATION	$162 000
2.0	TRANSPORTATION	29 000
3.0	ERECTION	137 000
4.0	ROTOR	329 000
5.0	DRIVE TRAIN	379 000
6.0	NACELLE	184 000
7.0	TOWER	271 000
8.0	INITIAL SPARES	35 000
8.1	NON-RECURRING	35 000
9.0	TOTAL INITIAL COST	$1 561 000
	FEE (10%)	156 000
	TOTAL TURNKEY	U.S. $1 717 000
10.0	ANNUAL OPERATIONS & MAINTENANCE	$ 15 000

SOURCE: MOD-2 MACHINE, NASA, LRC, USA.

TABLE 5
COST OF ELECTRICITY

- ○ COST OF ELECTRICITY $\quad COE = \dfrac{IC \times FCR + AOM}{AEP}$
- ○ FCR = ANNUALIZED FIXED CHARGE RATE = 18% PER YEAR
- ○ IC = TOTAL WTS COST = \$1,720,000 (1977 U.S. \$)
- ○ AOM = ANNUAL OPERATIONS & MAINTENANCE COST = \$15,000
- ○ AEP = ANNUAL ENERGY PRODUCTION = 9.75×10^6 KWH
- ○ COE = 3.3¢/KWH

SOURCE: MOD-2 MACHINE, NASA, LRC, U.S.A.

TABLE 6

CAPITAL COSTS FOR ELECTRICAL GENERATION PLANTS

(A) PLANT	(B) CAPITAL COSTS		(C) PROJECT COSTS		(D) FUEL COSTS
	US $/KW YEAR 1974	US $/KW YEAR 1983	FUEL SPECIFIC	SITE SPECIFIC	
OIL	300 - 500	800 - 1200	✓	✓	HIGH
COAL	400 - 600	1000 - 1400	✓	✓	AT PRESENT LOW
NUCLEAR	600 - 900	2000 - 3500	✓	✓	AT PRESENT VERY LOW
HYDRO	500 - 800	1000 - 2500		✓	ZERO
MINI-HYDRO	NOT WIDELY EXPLOITED	1200 - 4000		✓	ZERO
WIND	RESEARCH & DEVELOPMENT	500 - 1200		✓	ZERO

NOTES:

(A) REFERS TO LARGE SIZE UNITS;

(B) INDICATES THE CAPITAL COSTS FOR A MATURE COMMERCIAL PRODUCT;

(C) REFERS TO THE CHARACTERISTIC OF THE PLANT. "FUEL SPECIFIC" IMPLIES THAT GRADE OF FUEL USED AND THE ANTI-POLLUTION DEVICES REQUIRED WOULD INFLUENCE THE PROJECT COST. "SITE SPECIFIC" MEANS THAT DUE TO THE CHARACTERISTICS OF THE ENERGY SOURCE, THE PLANT HAS TO BE LOCATED AT THE RESOURCE SITE;

(D) REFERS TO FUEL COMPONENT COST ONLY FOR THE PLANT.

TABLE 7

COMPARATIVE COST OF ENERGY
OIL-FIRED PLANTS VERSUS WIND POWER PLANTS

CRUDE OIL PRICE US$/BARREL	NO.6 OIL COE ¢/kWh	NO.2 OIL COE ¢/kWh	WIND POWER COE, ¢/kWh MEAN ANNUAL WIND SPEED @ 6.26 m/s (14 mph)	WIND POWER COE, ¢/kWh MEAN ANNUAL WIND SPEED @ 8.05 m/s (18 mph)
2	0.32	0.35	5.12	2.85
10	1.59	1.73	5.12	2.85
18	2.86	3.11	5.12	2.85
26	4.13	4.49	5.12	2.85
36	5.40	5.87	5.12	2.85
42	6.67	7.25	5.12	2.85

SOURCE: REFERENCE 2

BASIS OF COE

- 18% FCR
- 1980 CAN. $

FIGURE 1
MATURITY ASSESSMENT OF SELECTED ADVANCED ENERGY TECHNOLOGIES

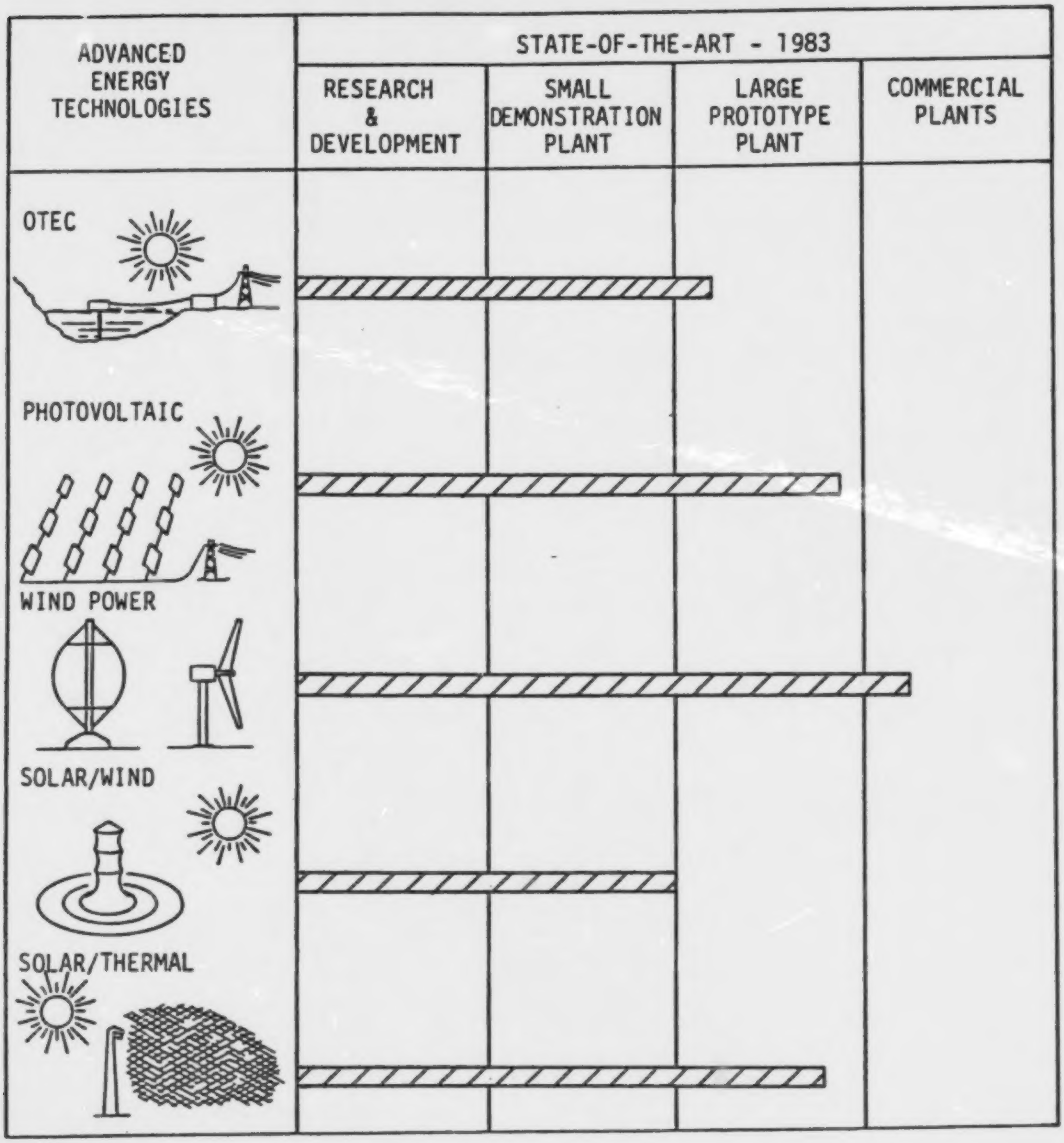
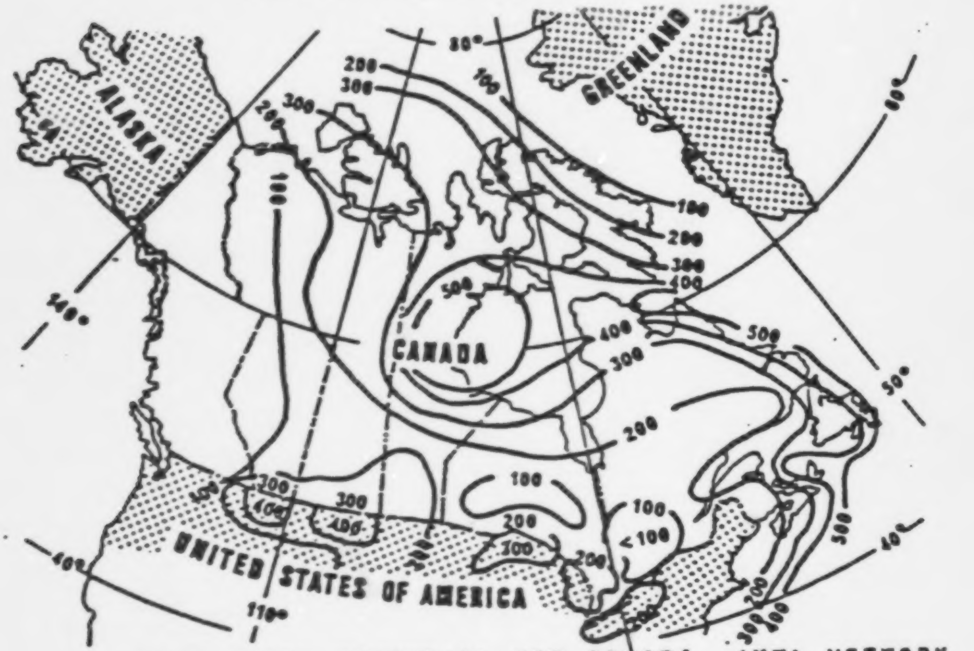


FIGURE 2
ANNUAL AVERAGE WIND POWER DENSITY
(W/m²) @ 30m HEIGHT


ALASKA
GREENLAND
CANADA
UNITED STATES OF AMERICA
80°
60°
50°
40°
140°
110°
100
200
300
400
500
<100

WIND POWER POTENTIAL FOR CANADA, (MW). NETWORK AREA + 150 km

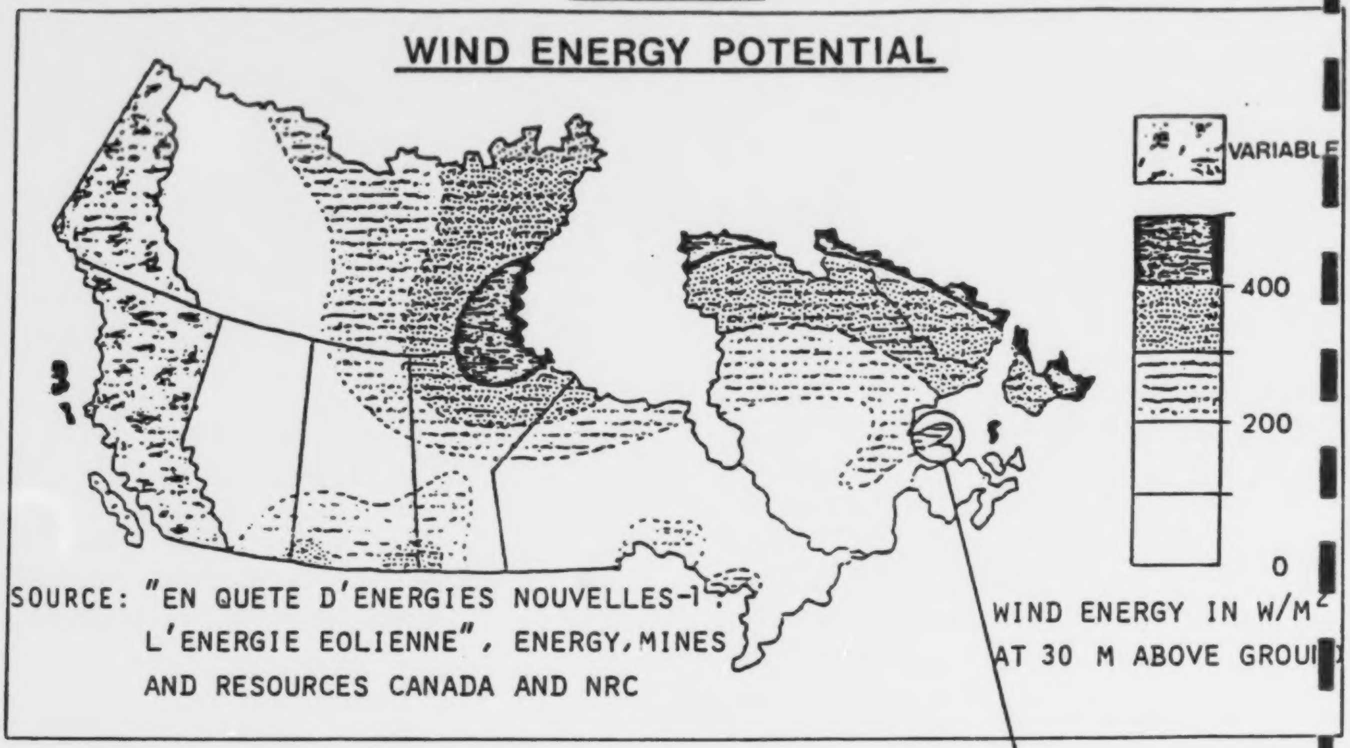
REGION	POWER DENSITY (W/m²) 100-200	200-300	300-400	400-500	>500	>100 @ 30 DIA	>100 @ 10 DIA
YUKON	-	-	-	-	-	-	-
N.W.T.	1 600	1 900	-	-	-	3 500	31 500
B.C.	-	-	-	-	-	-	-
ALBERTA	3 700	1 200	300	-	-	5 200	46 800
SASK.	4 600	4 000	1 400	-	-	10 000	90 000
MAN.	1 380	5 800	2 300	830	1 780	11 870	108 830
ONT.	7 500	-	-	-	-	7 500	87 500
QUEBEC	8 500	3 500	-	-	-	12 000	108 000
N.B.	1 000	-	-	-	-	1 000	9 000
N.S.	-	1 000	280	20	-	1 300	11 700
P.E.I.	-	-	200	-	-	280	1 800
NFLD.	1 000	1 400	4 000	1 300	700	8 400	75 800
TOTAL	29 280	18 800	8 480	2 150	2 480	60 970	548 730

PRINCIPAL SOURCE: NATIONAL RESEARCH COUNCIL, CANADA, 1977

NOTE: POTENTIAL BASED ON 30 & 10 DIAMETER SPACING BETWEEN WTGs

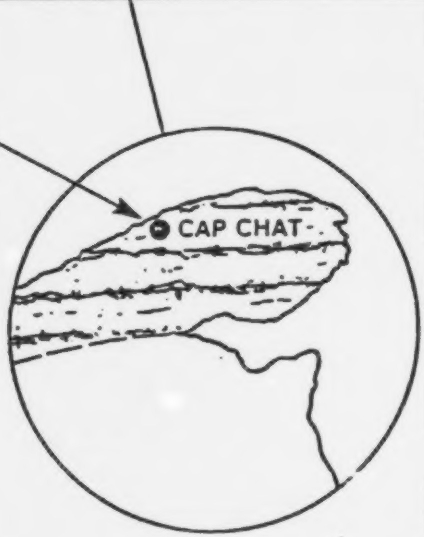
FIGURE 3

WIND ENERGY POTENTIAL



SOURCE: "EN QUETE D'ENERGIES NOUVELLES-1 : L'ENERGIE EOLIENNE", ENERGY, MINES AND RESOURCES CANADA AND NRC

WIND ENERGY IN W/M² AT 30 M ABOVE GROU



SITE OF EOLE AT LA FONDERIE NEAR CAP CHAT

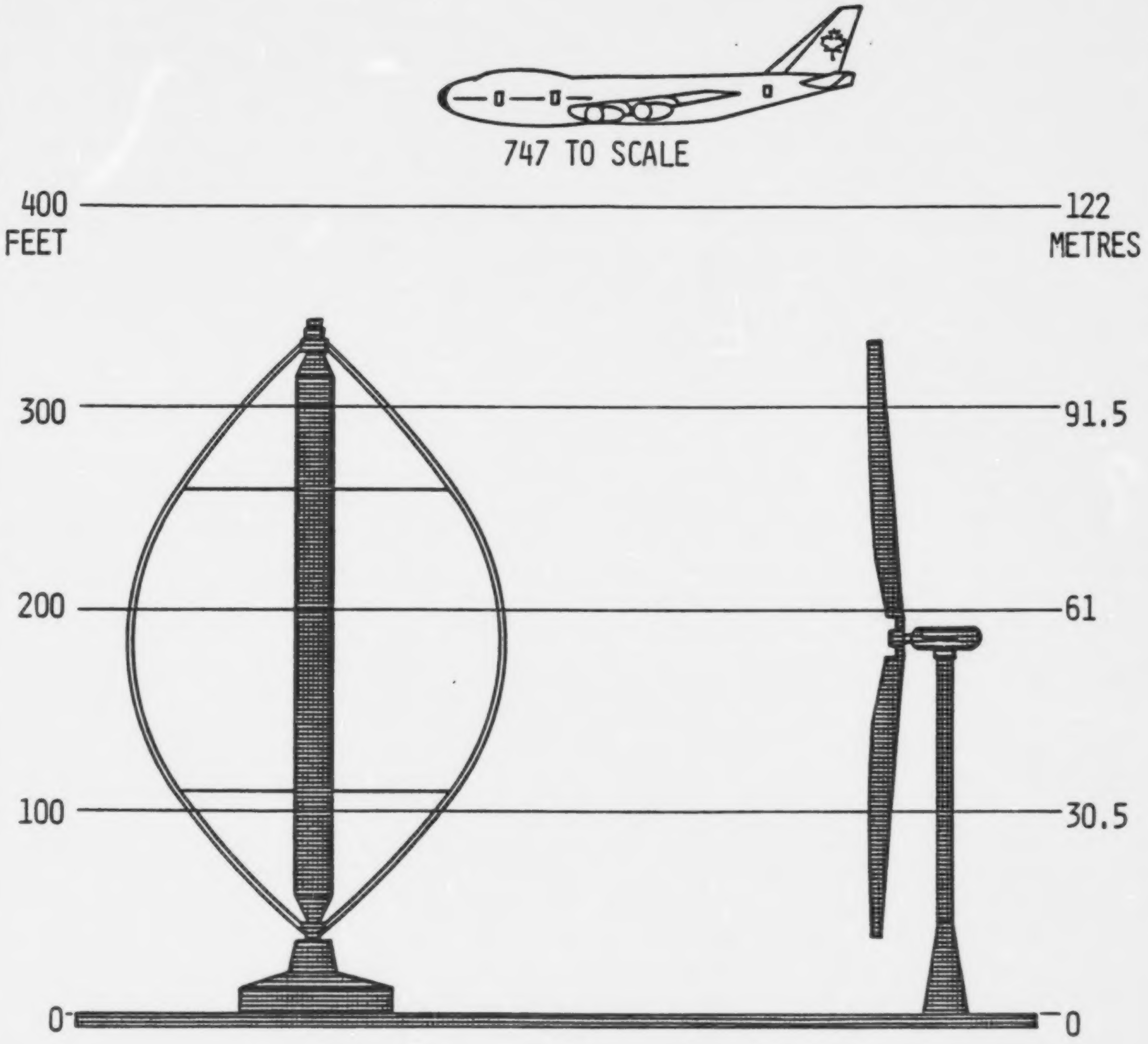
TOTAL INSTALLED ELECTRIC GENERATION CAPACITY IN QUEBEC (1983-85): 25,000 MW

WIND ENERGY POTENTIAL WITHIN 150 KM OF EXISTING ELECTRIC TRANSMISSION LINES IN QUEBEC : 110,000 MW

WIND ENERGY AT LA FONDERIE IS APPROXIMATELY 400 W/M² AT 30 M ABOVE GROUND LEVEL

THEREFORE, FOR A CORRECT ESTIMATION OF WIND ENERGY POTENTIAL OF A GIVEN SITE, IT IS ESSENTIAL THAT A WIND STUDY BE CARRIED OUT FOR EACH SPECIFIC SITE.

FIGURE 4
TYPES OF WTG's


747 TO SCALE
400
FEET
300
200
100
0
122
METRES
91.5
61
30.5
0

VAWTG
PROJECT EOLE 4 MW

HAWTG
MOD-2 2.5 - 3.8 MW

FIGURE 5 DEVELOPMENT OF HAWTG's

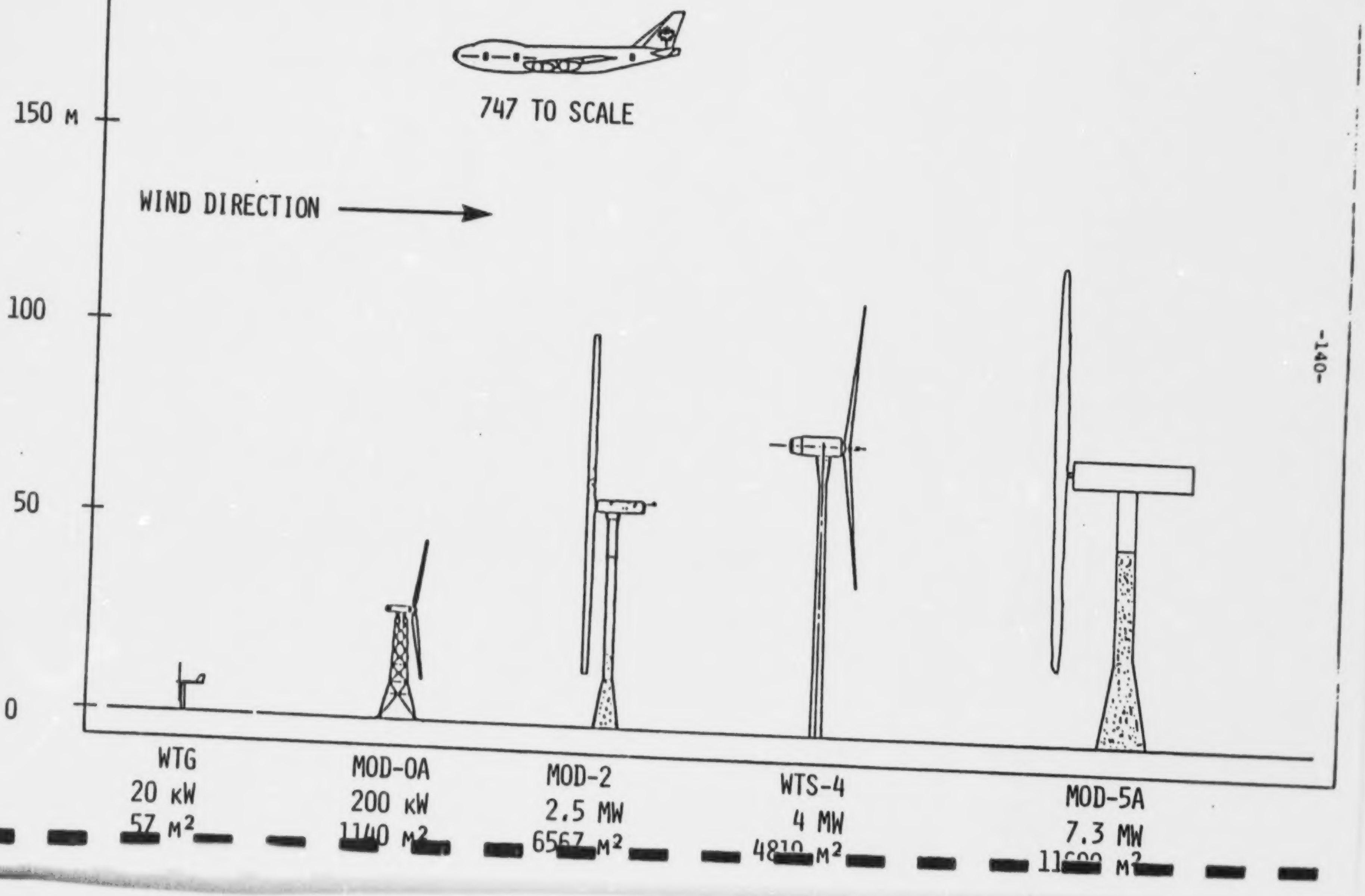

747 TO SCALE
150 M
100
50
0
WIND DIRECTION
WTG
20 kW
57 M²
MOD-0A
200 kW
1140 M²
MOD-2
2.5 MW
6567 M²
WTS-4
4 MW
4810 M²
MOD-5A
7.3 MW
11[illegible] M²

FIGURE 6
DEVELOPMENT OF VAWTG's

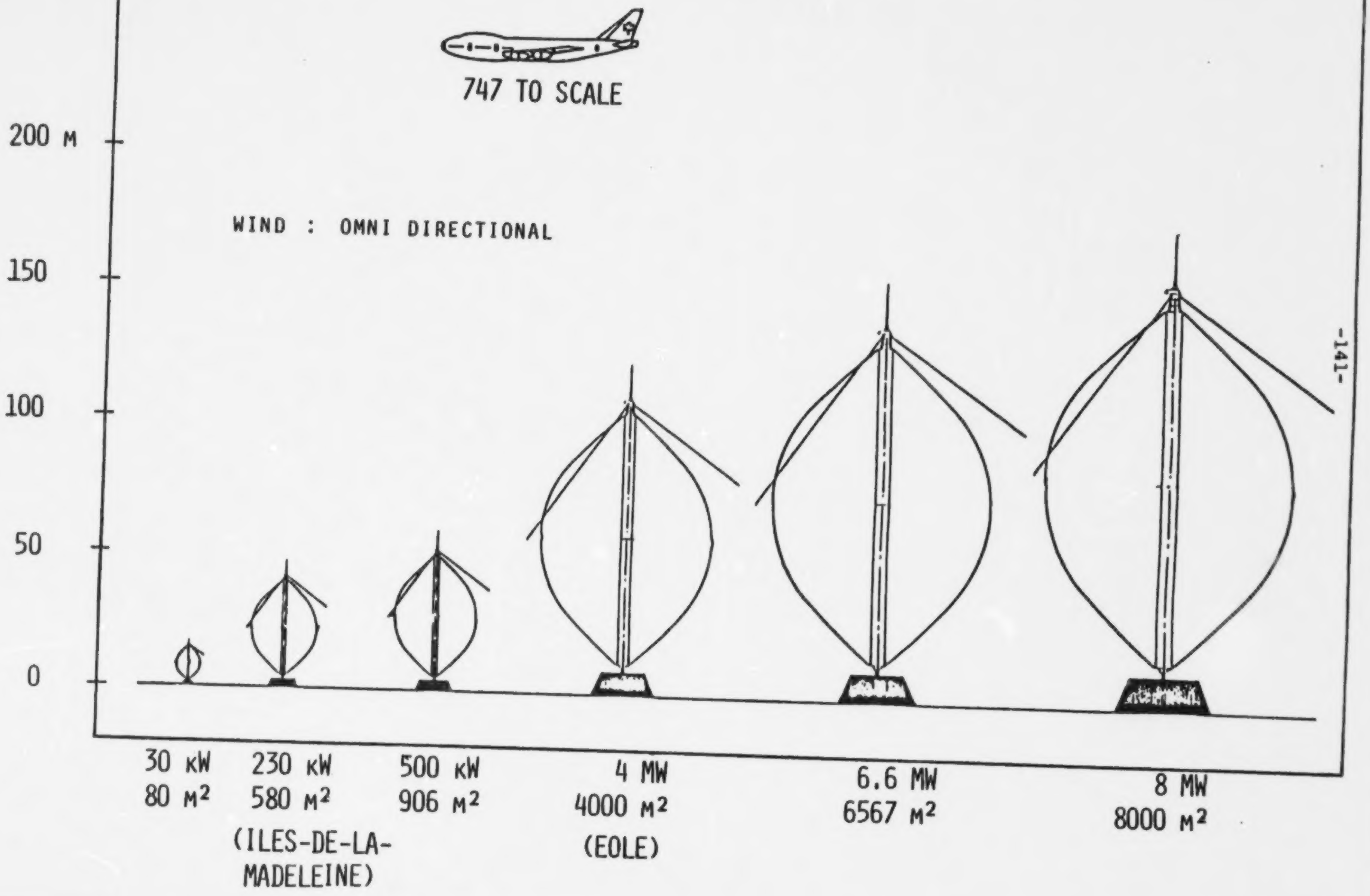

747 TO SCALE
WIND : OMNI DIRECTIONAL
200 M
150
100
50
0
30 kW
80 M²
230 kW
580 M²
500 kW
906 M²
(ILES-DE-LA-MADELEINE)
4 MW
4000 M²
(EOLE)
6.6 MW
6567 M²
8 MW
8000 M²

FIGURE 7
UTILIZATION SCHEMES FOR WTGs

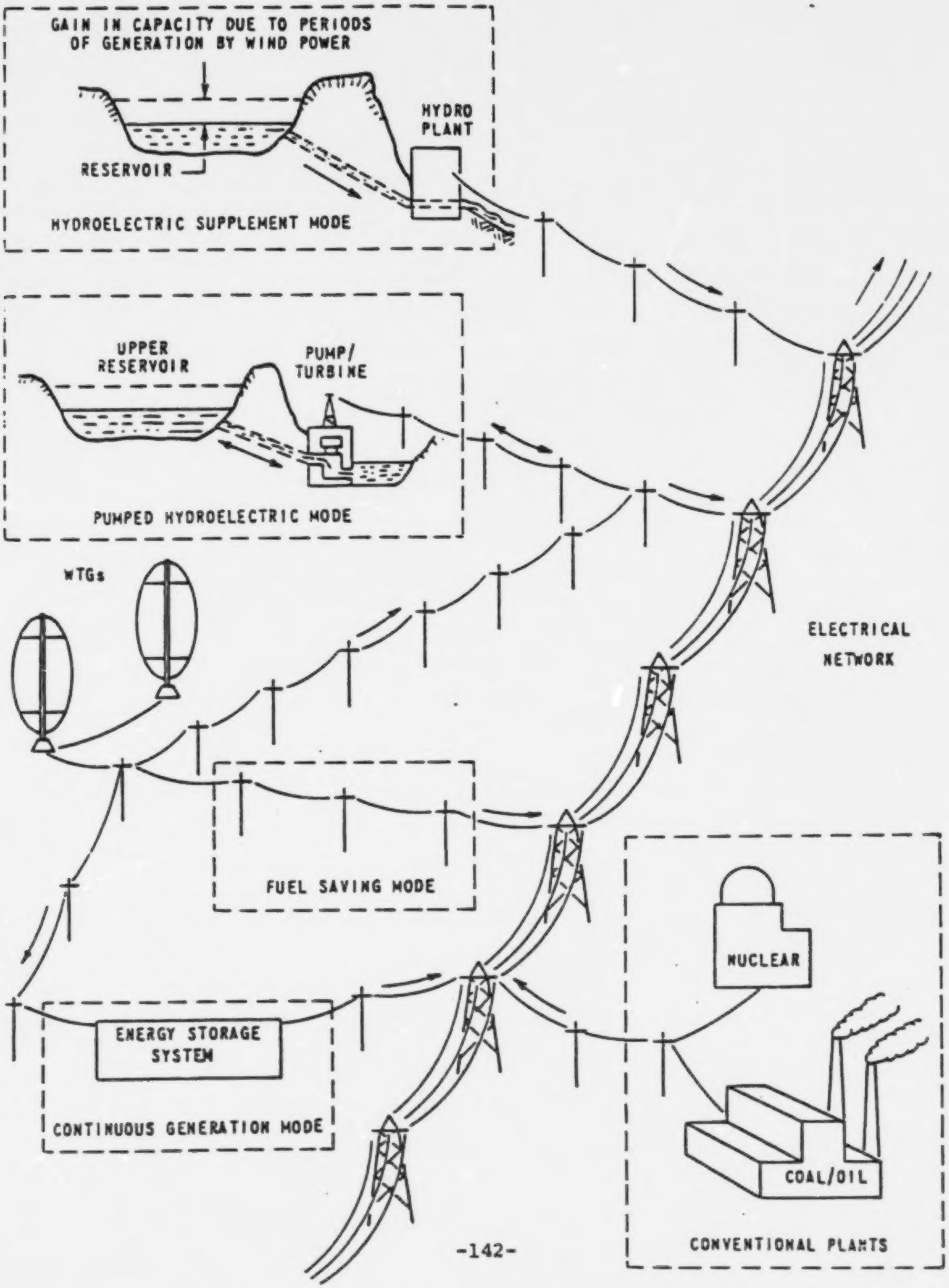
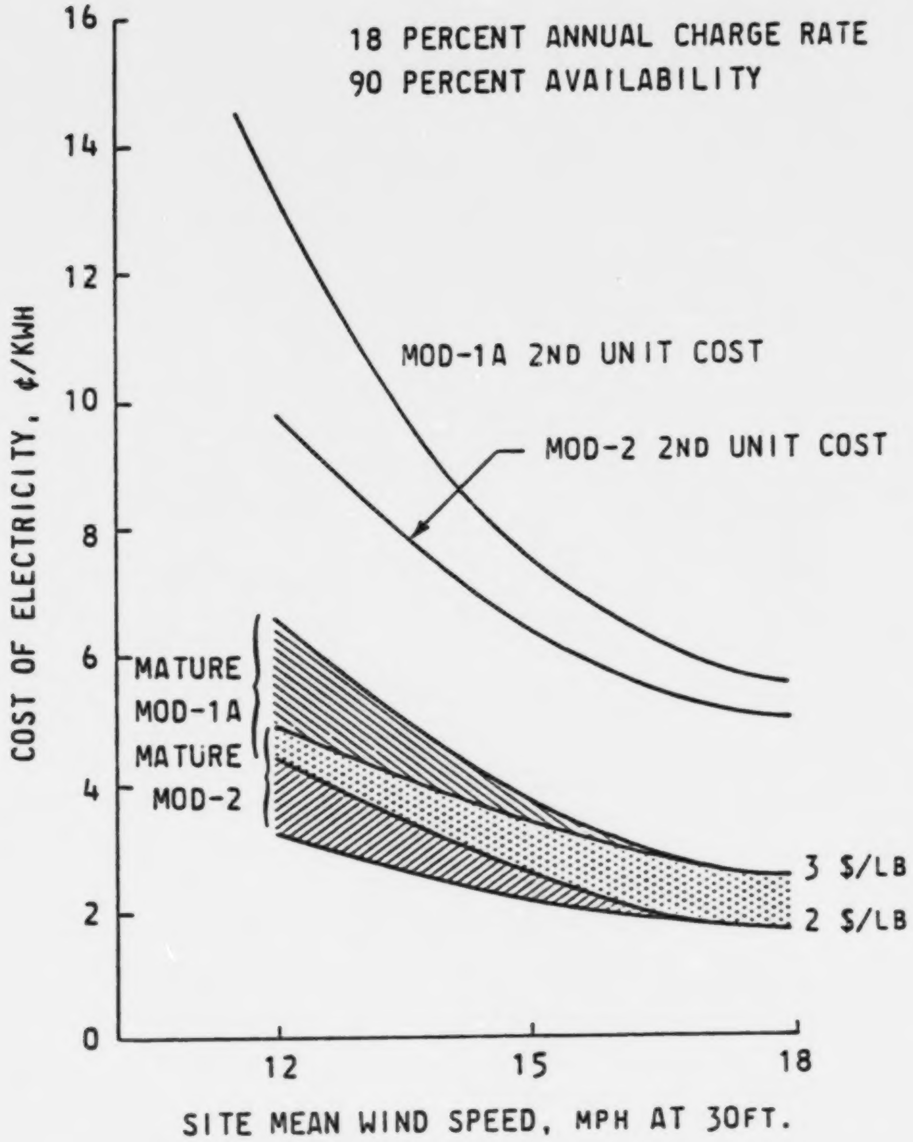

GAIN IN CAPACITY DUE TO PERIODS OF GENERATION BY WIND POWER
HYDRO PLANT
RESERVOIR
HYDROELECTRIC SUPPLEMENT MODE
UPPER RESERVOIR
PUMP/ TURBINE
PUMPED HYDROELECTRIC MODE
WTGs
ELECTRICAL NETWORK
FUEL SAVING MODE
NUCLEAR
ENERGY STORAGE SYSTEM
CONTINUOUS GENERATION MODE
COAL/OIL
CONVENTIONAL PLANTS

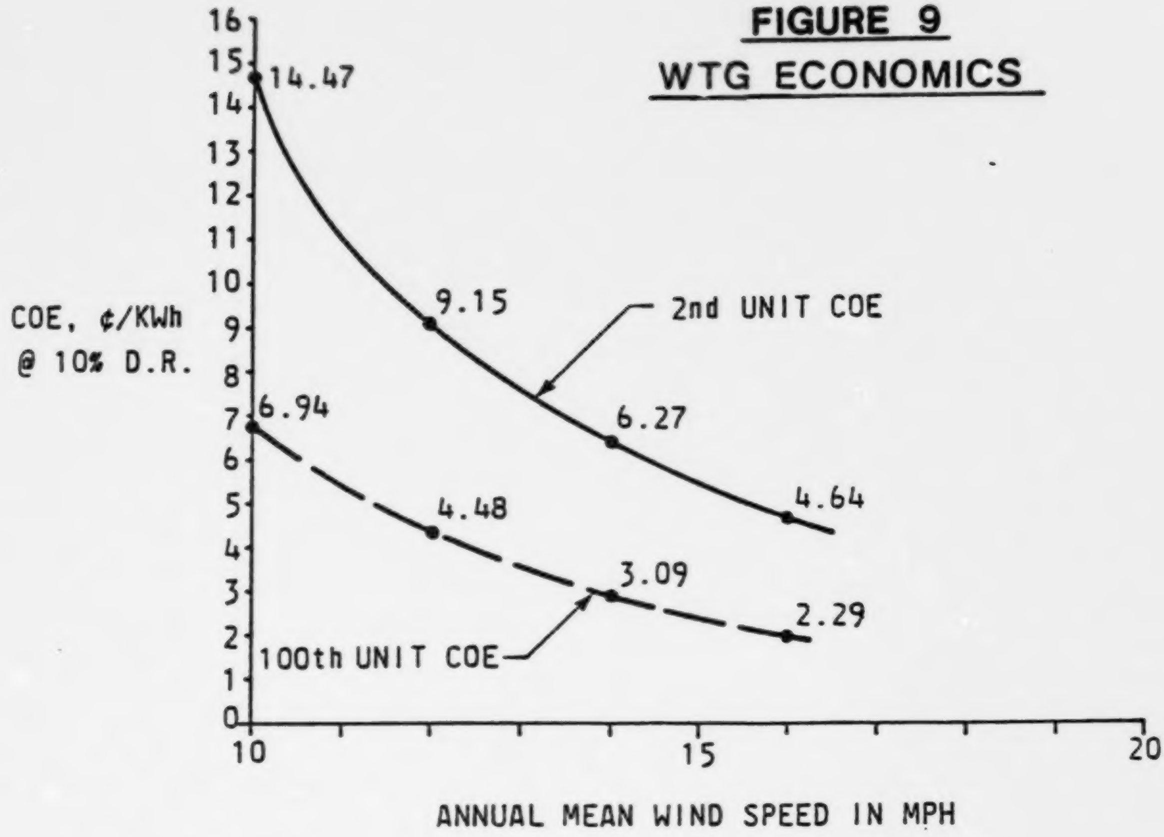
FIGURE 8

ESTIMATED COST-OF-ELECTRICITY FOR SECOND UNIT AND MATURE PRODUCTS



SOURCE: LARGE WIND TURBINE GENERATORS, NASA, LRC, USA.

FIGURE 9
WTG ECONOMICS



$$COE = \frac{(CC \times 10\%\ D.R) + (L.F \times O\ \&\ M)}{ANNUAL\ ENERGY} \times 100 = ¢/KWh$$

WIND SPEED mph	UNIT RATING MW	TOTAL INSTALLED COST, $ M (1980) CAN.		
		PROTOTYPE	2nd UNIT	100th UNIT
10	2.5	20	5.8	2.7
12	5	20	6.4	3.0
14 & 16	6.6	20	6.8	3.3

JOB CREATION

@ PRODUCTION RATE SCENERIO OF 20 UNITS/MONTH = 16,000 DIRECT JOBS

ENERGY PAY BACK

DEPENDING ON WIND REGIME = 6 TO 24 MONTHS

MARKET IMPLICATIONS FOR WIND TURBINES IN ISOLATED UTILITY GRIDS

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New York

Summary

This paper is directed toward the marketplace that has been perceived by the wind industry and its observers as a prospective major market for wind generators. But, as with any attractive market, ameliorating conditions exist which require that the developer entering this market be motivated by a strong entrepreneurial spirit. In this paper I wish to accomplish two things. In the first part I will present some slides giving an overview of our history. The second part approaches the remote utility market from two perspectives. The first section outlines the characteristics of the remote marketplace and itemizes some of the problems associated with the development of this market. The second section addresses the technical issues associated with isochronous operation and is based on WTG's experience with it's Cuttyhunk Island installation.

Operational Description of the MP-200

(SLIDES)

The rotor rotates at a constant 30 rpm. The tip flaps at the edge of each blade are mechanical stored energy devices that are hydraulically placed in plane to act as brakes. The 40:1 increasing gearbox steps up the rpm to 1200 rpm on the high speed shaft. A four pole synchronous generator at the Cuttyhunk installation produces power at 60 Hz. Note the hydraulic control system behind the generator which operates the tip flaps. It also operates the disc brake on the high speed shaft, the yaw drives and the yaw caliper brakes.

Power is transmitted down though the power cable. There are no slip rings on the power cable. We have a program that monitors the twists on the cable. It automatically unloads the twist through yaw drive of the nacelle in periods of low winds.

Here is a view of the tower which is preassembled before shipment. This looks like, and is, a beefy tower because the overall design concept of our machine is that we do not want to reach the first harmonic even in a worst case situation.

A view of the blade fabrication, utilizing basic aircraft technology. It is an all steel rotor, steel spar, steel ribs and a stainless steel skin.

This shot is of the drive train was taken in our shop prior to shipping this machine to Nova Scotia. You can see the transmission mounted on the bed plate. Behind that is the generator. To the right of the generator is a manual control panel for the operation of the machine on top of the tower. Everything can be accomplished from the top of the tower that can be accomplished from the control house except synchronizing with the grid. Behind the control panel is the hydraulic accumulator and the hydraulic pumps. At the base of the stand-off you see the two little rectangular boxes sticking down, the third one you can't see. Those are the hydraulic yaw caliper brakes. When the machine yaws, these brakes are released. With the completion of the yaw, the brakes are automatically reset, clamping the drive train to the tower top.

The tip flaps, yaw caliper brakes, and high speed shaft disc brakes are all hydraulically powered, mechanically stored energy devices. Hydraulic pressure opens up the brakes against a compressed spring.

This view shows one of the three shipments for a completed machine. These are the drive train components, which are completely shop tested, and the top of the tower. The other two shipments are for the tower and the blades.

The tower is a pin truss tower. This photo gives you some idea of the fabrication of the tower. Normal time to install it is two and a half days from the time it arrives on the site, assuming the foundation is in place.

This photo shows the lift of the drive train.

Here is the way the blades arrive. The tip flaps are packed horizontally underneath the blades.

The MP-200 system utilizes a fixed pitch hub. What we are looking at is the levelling and setting of the blades into the hub. In the lower right hand corner are the hub halves that will be clamped and torqued.

The tip flaps are installed and the lift begins. The lift is accomplished in the horizontal position to approximately half the tower height. At that time you let out one of the cables, dropping the rotor to a vertical position and then the lift aligns the hub to the low speed shaft.

Looking down on the low speed shaft. This is the hub side of the shaft. The shaft is keyed and 3,500 ft-lb of torque is put on the bolts.

Note in the previous slide that all of the thrust and load bearings are incorporated inside the transmission and are bathed in the oil bath of the transmission.

This shot, looking back on the generator, was taken with a hand held camera while standing inside the machine cabin. There is a man on the right to give you some idea of scale. This machine is operating at synchronous speed. The only way that you can tell that the machine is running is that you can't see the tap heads on the flexible coupling.

From the same location but looking forward on the high speed shaft. That is the back of the transmission showing the combination parking and service brakes. Again note the flexible coupling in operation on the shaft.

The control house equipment. Note the CRT for local monitoring. Monitored parameters are updated twice per second.

Here is an illustrated printout of the monitoring display. Above the dotted line are the parameters that are monitored, displayed and can be printed as frequently as the program displays it on a remote teletype. These include: time, date, average power, alarm status, alarm code, the average and instantaneous wind velocity, average yaw direction, cable turns, line voltage between phases, turbine voltage and amps between phases, kilo volt-amps, power factor, kilowatts, reactive power, and wind turbine generator frequency, rpm and temperature.

If there is a computer error, there will be a computer error code. Two kinds of alarm can occur. A 'normal operation alarm', such as low wind speed, when the machine will take itself off-line automatically, print out the status, then automatically return itself to the line when the wind picks up sufficiently. An 'emergency alarm' for an emergency shut down will open the contactor. At that point the operator must physically go up to the top of the tower, correct the mechanical fault, and put the machine back on line. The alarm status for either normal or emergency operation alarms will print out on the teletype, with the time.

As is the case on some machines, you have a supervisory menu below for the key-in commands from the remote teletype.

Regarding the average wind velocity, we do not cut-in at 8 mph at many sites, although we could, because the wind fluctuates too much between 7-8-9 mph. We do not want to cut in until the average wind speed is enough to sustain operation. Same procedure exists with yaw direction. We will average the yaw direction, then correct within 6 degrees of the yaw. This is done periodically so there is not constant hunting.

The first production machine was installed at Wreck Cove, Nova Scotia in October, 1981. The machine pumps water into a hydro resevoir from a lake at a lower level, thereby increasing the capacity factor of that plant.

The second production machine was installed for Pacific Power and Light in Whiskey Run, Oregon in October 1981 within 100 meters of the Pacific Ocean.

The fourth production machine was purchased by the U.K. CEGB and was done as a joint venture with James Howden & Co. from Glasgow, Scotland. Commissioned in October 1982, it is located at the Camarthan Bay thermal plant. Note in this slide the compatibility of wind power with conventional power.

The third machine and 6th, 7th and 8th machines are installed in Equinox, Vermont near Manchester at an elevation of 3400 feet. We have a great deal of experience at this location with cold weather operation. We have encountered wind chill factors of 140 degrees Fahrenheit below zero at this, our coldest installation.

This is our prototype installed at Cuttyhunk Island, Massachusetts installed in June, 1977. For those of you familiar with our literature, this is the picture we use of the MP1-200 prototype on Cuttyhunk. A picturesque shot of the island.

This is a shot of the control house at Cuttyhunk illustrating the five generators with a total installed capacity of 465 kW.

1.0 The Marketplace

In the continental United States, few electric users exist who are not presently served by a utility. In the past 40 years the Rural Electricification Administration has provided low cost electrical power throughout the 46 states within their jurisdiction. Those areas not presently interconnected are areas in which there exists little need for power. For example, in the East there are only a few logging and mining operations in Northern Maine that are not interconnected, and the Midwest and Western areas have expanses of agricultural areas without electrical service.

However, in Alaska, only 5% of the land area is served by an interconnected system. The rest of the area is dependent on isolated power systems. As an example, most of the larger isolated systems are part of the REA system in Alaska, while many others are not part of the system. These isolated systems exist because it is currently not feasible to extend the area of interconnected service across the large unpopulated distances that separate individual power sources. These distances, coupled with the short transportation season, yield a high fuel cost to these remote systems.

The marketplace characteristics of the Canadian remote utilities are similar to Alaska. Isolated utilities using diesel generators are found in the Northwest Territories, the Yukon, northern Ontario, Manitoba, Saskatchewan, Alberta, and Quebec. Again, high fuel costs are a consequence of the requirement to transport fuel to the site.

The Caribbean is also an attractive market prospect due to the benign ambient temperature, constant trade winds, and a declining reserve of petroleum and gas. Market studies have been conducted outlining the potential for wind generation in the Caribbean area. However, numerous sources have indicated to WTG that, when a global perspective of isolated utilities is considered, the North American market of isolated utilities will account for an inconsequential percentage of the total market. Therefore, the following characteristics of the market, although directed to the areas referenced, appear to exist for any isolated utility.

2.0 Characteristics of the marketplace

The following comments relate to the general characteristics of an isolated utility:

2.1 Although economic pressures of the last decade have forced utilites to institute comprehensive energy plans, few isolated utilities have incorporated wind or other alternative energy sources within their planned capacity replacement or expansion.

Various reasons exist for this lack of recognition. The main factors are the traditional utility approach that rarely looks beyond conventional generating sources and the belief that alternative energy sources are not mature products. The consequence of this thinking requires that the introduction of wind generation to an isolated utility will entail an educational process presenting the technical, reliability and economic issues to the utility's engineers, planners and management.

2.2 Frequently wind data is unavailable to permit economic assessment.

Understandably, the more remote the utility, the less likelihood of encountering an existing wind data base. Without an indication of the wind resource, it is difficult to evaluate a project's feasibility, and even if indicators provide evidence of a viable resource, some documentation will be necessary. Consequently, there may be a quiescent period during the data acquisition when the interest may wane, management may change, or a more attractive alternative arise.

2.3 The same barriers exist in the isolated market that are found in the commercial windfarm development, namely lack of knowledge regarding the technology, high first cost, non-competitiveness with conventional energy sources, anxiety over untried technology, and the lack of long term operational data and service life.

These problems are compounded by the greater difficulty in communications due to the nature of the market and uncertainty as to funding sources.

2.4 Frequently, the isolated utility will be in the position of having no financial reserves due to increasing operating costs. When the isolated utility is not associated with a utility network, the available reserve funds will most likely b used to repair existing generation or replace generation with comparable equipment.

To develop this isolated market, creative and non-conventional financing or lease agreements must be negotiated based on the long-term economics of the wind generation project.

3.0 The market characteristics expressed above may be best approached by breaking these concerns into the following categories:

3.1 Viability: Initially, a potential user of WECS may be familiar with the development of the industry. Unfortunately, much of the information found in the press has focused on system failures. It is only recently that viable operations have been newsworthy.

Manufacturers who expect to exploit the remote marketplace must be prepared to document the success of existing projects and emphasize similar remote applications, installed in similar environments, and presently in operation.

3.2 Reliability: Because of the random nature of the prime mover, potential WECS users must propose complete systems that will operate in parallel with existing generating sources while maintaining or increasing system reliability.

3.3 Maintainability: As the remote market is frequently located in hostile environments, the durability of the wind generator must be demonstrated with respect to temperature extremes, high winds, salinity or moisture content, and other site specific environmental factors. These factors become more critical in those markets where system monitoring and service facilities are at a minimum.

Service is a critical factor. The availability of support personnel, the maintenance training programs, and support for maintenance personnel must be considered as the success of the operation will depend on its continued performance. The remoteness of the market makes the supply of replacement parts and the availability of technical assistance a critical factor i the development of the remote market.

3.4 Cost: System cost is perhaps the most critical factor in the development of this market. It is apparent that the logistics of the site will affect the cost of sales, the transportation of equipment, the installation costs, and the service cost. Further, to ensure system reliability, increased application engineering costs will be encountered.

However, the same factors that increase the cost of installation and operation for a WECS, also increase the system costs for the remote utility. Therefore, on a life cycle cost basis, the economic justification exists for a WECS installation providing that factors of viability, reliability and maintenance have been adequately addressed.

It is obvious from the above description that the remote marketplace is one that requires a clearly defined and sustaining market plan. Those manufacturers that approach this market must be able to demonstrate the operational history of their equipment and be sufficiently financed to support the gradual growth rate expected in this market.

4.0 Isochronous Operation

For a wind generator to contribute reliably in a remote, isolated grid, the wind generator's control system must satisfy many unique control requirements (for wind turbines) in addition to the numerous conventional requirements of an infinite bus application. In either case, the wind system must be completely automatic, fully protected against system and turbine faults, and must be capable of synchronizing and controlling the average power output into the utility network. Additionally, an isochronous generating system must be capable of operating as a lead generator, maintaining responsibility for the control of system frequency, voltage, and in most cases the generation mix.

Conventional small generation plants, such as diesels, gas turbine, and hydro units are fitted with hydraulic (and more recently electric) speed governors. Regulation of the speed and/or power of the generator is accomplished by varying the fuel supply rate to the prime mover as a function of generator speed and consequently the system frequency. In typical multi-unit generation systems there is a lead unit with the primary responsibility of maintaining system frequency as the effective load changes. Other connected units are generally operated as base load generators and are adjusted to maintain a constant loading regardless of variations in system frequency.

There are many degrees within these two spectra of unit operation that are typically encountered which must allow several generators to divide changes in load, based upon a pre-set proportionality. When the highly dynamic and random nature of wind generation is introduced into such systems, their effect is generally modeled as a "negative load". Accordingly, the existing lead generator must adjust to compensate for the effective change in generator mix, as if the connected load was varying.

Many factors influence the control performance of these types of generating system. Among these factors are the size and type of the prime mover, the type of governor, the inertia of turbine and power source. In the case of wind turbines, the source of power has the dominating influence on control performance. Typically, most manufacturers use a variable pitch method for controlling the turbine's torque output.

Rather than attempt to contend with the inherent lags and non-linearities of the variable pitch control system approach, WTG has designed a speed governing system using a computer applied load to the generator to control the net equivalent torque output to the utility system. Aerodynamic control of the turbine's torque, by means of "partial-span" blade angle control, (or the tip flaps) is used to establish a mean operating torque level. The high speed control of the turbine's speed is accomplished by rapidly adding or subtracting the desired amount of generator loading so as to establish a constant generator speed (and in some circumstances a constant maximum power output level).

In addition to maintaining a set speed and generator frequency, this control system essentially dampens the higher frequency variations in output power in a sufficient manner so as to allow the proper response from the conventional hydraulic governors used by most small generating systems. A drooping characteristic (the sensitivity by which a corresponding change in applied load shall affect the throttle of the prime mover) can be achieved automatically by enabling a second inner control loop using the turbine power output as the controlled variable (in addition to the primary speed control loop).

5.0 Cuttyhunk Operation

WTG's experience in the area of isochronous operation dates back to the installation of the MP1-200 prototype on Cuttyhunk Island, MA in June, 1977.

The electrical generation for Cuttyhunk Island consists of six diesel sets ranging in capacity from 30 kW to 175 kW. The total installed capacity of the island is 465 kW with all start-up, synchronization and shutdown operations performed manually.

The MP1-200 prototype development continued from the date of installation in 1977, until the summer of 1980, with the majority of the research devoted to the development of a control system that would achieve the objectives discussed previously. This development activity proceeded until the wind turbine system was capable of operating within the same performance envelope as the diesel generators. It is important to note that these objectives were met without modifying the existing diesel controls or incorporating secondary control system interconnections.

In practice, the regulation of generator speed is very good in winds up to 25 mph, degrading above this speed due to the higher frequency gust components typical of high wind velocities. In a "stand-alone" operating mode, worst case frequency deviations on the order of plus or minus 0.35 Hz have been achieved within the operating limits of the wind turbine. As would be expected, his accuracy is greatly increased when operating in synchronism with a stable source of equal or greater capacity.

With the diesels' governor set for about 2 percent speed droop, the load will be divided proportionally according to the diesel generators' speed setting (given the average sizes of the diesel generators on Cuttyhunk). When the output of the MP1-200 is sufficient to carry the island's load, the unit will do so at a nominal frquency of 60.2 Hz. In this situation, the diesel set(s) will be idling. Should the wind velocity decrease, decreasing the generator's power output, the diesel set will begin to pick up the proportion of the load dropped by the wind generator. System frequency could fall as low as 59.7 Hz when the diesel set is fully loaded and the wind generator is idling. This condition usually occurs when the wind velocity varies about the cut-in wind velocity. When the output of the MP1-200 is greater than the island's demand, the unused power is dissipated through the load bank.

The operation of the Cuttyhunk machine was discontinued in the fall of 1981 due to the lack of a purchase power agreement with the local utility and WTG's lack of financial resources to continue the operation without a source of revenues. At the time operation was discontinued, the MP1-200 had over 2,500 hours of electrical operation and had generated over 175,000 kWh. At this time, an agreement has been reached with the Island to purchase power and WTG is in the process of updating the mechanical and electrical components of the unit to incorporate modifications that have been developed in subsequent units.

Any questions?

Q. Why don't you put a windfarm of those out in California?

A. We had hoped to do that this year. We expect to be there next year.

Q. Do you mean that there were times when that wind turbine provided the island's total needs for electricity?

A. Oh yes, definitely.

Q. What is the longest period of time?

A. Off hand I don't know. I would estimate four to six hours, depending on the consistency of the wind.

Q. What is the nature of the icing problems that you encountered in Vermont? What percentage of the time was the machine down due to icing?

A. I don't know if we've looked at it in terms of percentage of time. We have a control feature, simple in operation, to detect icing. "When the anemometer ices over, it means the machine doesn't start up" - being a little bit facetious there. We have encountered a lot of experience with icing. Sensors did not read accurately in the low temperatures, we had to put localized heating elements at those sensors. We also specified synthetic lubricants for the hydraulic system. As a percentage of time,..... Historically icing is encountered in the early winter months but not past that time.

Q. Could you shed some light on the 'old wives tale' of diesel operation and very low loads? You mentioned modes of operation where the diesel was idling. Various operators in our experience claim running diesels at less than say 20-50% of rated power causes increased maintenance. What is your experience on Cuttyhunk Island?

A. You are referring to 'wet stacking', where in lower loading conditions you get oil dilution with the fuel. Unfortunately, I am not the proper person to respond to your question. All I can say is that we recognize the fact that this is a problem and that more research should be done. From our experience we don't have enough information to state qualitatively what should be done. With our prototype, we avoid this by operating quite frequently with the 30 kW diesel. We have a good selection of units from 30 kW to 175 kW.

Q. How many do you have installed?

A. We have eight installed right now. For our ninth unit, our first manufactured MP-600, we will be delivering to the site on Lake Erie next month for installation under government contract by spring 1984. The rotor is 125 feet in diameter with hub height of 120 feet. The machine is rated at 600 kW with maximum power of 850 kW.

Thank you.

MP-200 at Equinox

THE 300 KW HAWT SYSTEM IN THE ORKNEY ISLANDS

Alan Brown, engineer
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Glasgow, Scotland

INTRODUCTION

A 300 kW, 22 m diameter wind turbine has been designed by James Howden and Company, and erected on the North of Scotland Hydro-Electric Board site at Burgar Hill, Orkney. A particularly suitable application of wind energy is for islands or remote communities which depend on diesel generators for their electricity supply. The addition of a wind turbine to such a system can save a significant amount of expensive fuel. In designing a wind turbine system for such locations, there are particular features which should be incorporated. The aerogenerator must be capable of transportation and erection without the use of large cranes, it must be simple to operate, have a high reliability, and must be capable of generating into a small system without causing unacceptable power and voltage variations.

This paper describes the Howden HWP-300 aerogenerator and its design concepts.

TEST SITE

The aerogenerator is installed on a site owned by the North of Scotland Hydro-Electric Board who are responsible for electricity supply in the North Mainland and Islands off the North and West Coasts of Scotland. The Burgar Hill Site is situated on the mainland island of the Orkneys, which with a lititude of 59° north and penetrating the temperature storm belt have a high frequency of gales and strong winds. The site has been extensively monitored under and independent study funded by the U.K. Department of Energy and from the results of this study the mean annual wind speed at the hub height of 22m has been estimated at 10.3m/s (23mph) with a 50 year 3 second maximum gust of 67 m/s (150mph). This makes the site an ideal proving ground for the robustness and reliability of the system, although being so remote does cause communication problems.

DESIGN OPTIONS

During the initial design stages various design options were considered, the chosen features and the reasons for their choice are listed below.

a) Horizontal Axis Most practical experience is available with this design. The rotor could be designed to be self starting, important on small systems where motoring a large rotor up to speed could cause unacceptable variations in the supply voltage.

b) Upwind Rotor This gives lower blade loads and less effect on power output of tower shawdow.

c) 3 Blades Three blades give a smoother power output than two blades and do not required a teetered rotor to reduce loads on the structure. Three blades are dynamically balanced in yaw allowing a simple direct yaw drive to be used.

d) Tip Control Full span pitch control is not necessary to achieve the required degree of control. The use of variable pitch tips, enables the main blade root connection to be of simple rigid construction. The tips have a relatively slow response avoiding the complexity and high fatigue cycles of a rapid response system. The tips are used for speed control durng starting or stopping cycles, and for power trimming above 17m/s wind speed.

e) No coning or tilt in rotor axis Coning is unnecessary since the machine has a powered yaw system. Tilt is not required to give a suitable blade to tower clearance because a tubular tower is used.

f) Fixed Speed Operation Variable speed operation was assessed, but it was found that the extra power output does not compensate for the additional cost and complexity.

g) Brake on low speed shaft For maximum safety, the brake is as close to the rotor as possible and has the minium number of mechanical connection between the disc and rotor. In this way, the braking forces are not transmitted through the gearbox.

h) Separate low speed shaft bearings The rotor is not mounted directly on the gearbox input shaft allowing the gearbox to be maintained or removed without disturbing the rotor. The low speed shaft bearings are of split design to simplify bearing replacement.

i) Synchronous Generator This type of generator is more suitable for small distribution systems than induction generators, since these can cause unacceptable voltage variations due to current inrush and rective power demand during grid connection.

j) Tubular Tower This is more aesthetic than a lattice tower and gives protected access to the nacelle for inspection and maintenance. Provision is made for access to the blade tip mechanism without requiring additional equipment such as portable platforms. The base of the tower is capable of housing all control equipment, no separate control cabin being required.

ROTOR DESIGN

The bending moment distribution and maximum blade root bending moment associated with a 67m/s (150mph) gust of 3 second duration have had a dominant influence on the structural design. With the rotor parked in any attitude, all parts of the machine are designed to withstand the 67m/s gust with adequate safety margins, and retrospective analysis shows that in fact it would require a gust of 94m/s to bring any point of the structure to the point of damage. The main structural component of the blade is Khaya Ivorensis, an African mahogany which is commercially available in the U.K. in suitable veneers (4mm thick). Blade details are shown in Figure 2.

The techniques used in joining the blade to the hub have been developed from work which NASA undertook on the Mod-OA machines. The blade root attachment is made using 20 high tensile steel studs embeded in the wood epoxy matrix using a carbon fibre filled exposy resin.

Tensile and fatigue tests were carried out on individual stud and laminate specimens and a fatigue test on a complete root section and rotor hub.

The exposed surfaces of the blade are skinned with a woven glass cloth which increases the thickness of the final epoxy layer and adds to abrasion resistance. The leading edge of the blade has in addition 100mm wide polyurethane anti-abrasion tape. The blade tip and outermost 50mm of the main blade are covered by expanded aluminium mesh to provide protection lightningstrikes. Aluminium strips are used for the down conductors. In the main blade leading and trailing edges.

Each variable pitch blade tip incorporates an actuator for control of the tip position. The actuator operates in a failsafe mode, hydraulic pressure being required to hold the tips in the run position against the action of a spring and centrifugal force. Hydraulic fluid is passed to the tips via a hydraulic hose mounted in a plastic tube which is built into the main blade. The plastic tube allows the blade to be easily installed or replaced. The blade tips are attached to the main blade using a similar but smaller stud arrangement to the main blade root connection.

NACELLE EQUIPMENT

The low speed shaft forms an important link in the drive train assembly. It is capable of transmitting the full range of torque produced by the rotor and is designed to withstand a wide range of fault conditions as well as the normal gravity and aerodynamic loadings.

The brake disc is bolted to the low speed shaft through an integral forged hub. Twin spring applied, hydraullically released, fail safe calipers are used, balancing the breaking forces without loading the shaft bearings. The brake system is capable of stopping the rotor from an overspeed condition without the use of the blade tips. A mechanical shaft lock is provided to positively lock the shaft during maintenance.

The gearbox is a standard proprietary 3 stage speed increasing 33 to 1 ratio drive. The gearbox shafts run in roller bearings in a rigid cast iron casing. Splash lubrication is used with a mechanically driven cooling fan mounted on an extension to the intermediate shaft. A sensor is mounted in the sump to shut down the system in the event of high temperatures.

A fluid coupling is mounted on the output shaft of the gearbox. This is used to introduce damping into the drive system, reducing torsional oscillations and limiting the effects of wind gusts.

A freewheel coupling is mounted on the generator input shaft. This reduces the time taken to synchronise in gusting conditions, and prevents the rotor from being motored by the generator in low winds.

The generator is a standard, off-the-shelf, 4 pole, two bearing synchronous machine delivering alternating current. The output from the generator is transmitted directly to the tower base via twistable cables. The generator is designed with a self contained cooling system. Ambient air is drawn into the machine through louvered openings in the floor of the nacelle and the warm air is exhausted to the nacelle interior. Thermocouples are incorporated in the stator windings for over temperature protection.

The generator is fully protected for use in a marine environment and is fitted with anti-condensation heaters.

The yaw system is powered by twin direct drive, low speed axial piston motors. A large diameter disc brake with three spring applied hyraulic release calipers is used to damp out any oscillating forces when yawing and to lock the nacelle in the desired operating position. Full access can be gained to all the yaw system components from the tower interior. A system is provided to mechanically lock the yaw drive for maintenance.

A cabin control panel is provided in the nacelle as a maintenance aid. This enables the operator, while in the nacelle, to operate the various hydraulic solenoid valves, checking that the brakes, tips and yaw mechanisms function correctly.

TOWER AND FOUNDATION

The tower is in the form of a hollow cylinder of 1.82 metres outside diameter. The base which houses the control and instrumentation equipment is a conical section with a height of 5m and a base diameter of 4m. The tower base incorporates the access door and the aerogenerator erection hinge. The tower is built up from a number of sections for ease of transport and erection. Each section has internal flanges for connection to its neighbour, and longitudinal stiffeners welded to the inside. Access from the control room in the tower base to the nacelle is by internal ladders with intermediate platforms at three levels. A folding platform is provided in the tower mid-section for access to the blade tip mechanism.

A reinforced concrete gravity foundation is used. The base ring and bottom half of the erection hinge are bolted to the foundation using cast-in holding down bolts. The tower has been designed as a soft system, the first natural frequency of 1.8Hz being below the blade passing frequency.

POWER AND CONTROL SYSTEM

The electrical panels were designed as three distinct units for ease of handling and to fit neatly into the base of the tower. The panels house the switchgear, instrumentation and computer respectively and are interconnected via a plug and socket arrangement. This method of interconnection greatly helps to reduce the site installation time for the panels.

The switchgear panel contains the grid and generator fused isolators, main circuit breaker and the main contactor. This panel allows the power from the generator to be fed to the grid. In addition it provides power for the hydraulic pump motor, maintenance crane, lighting, heating and small power outlets. The auxiliaries are provided with lockable isolation in order to comply with the 'permit for work' scheme. The auxiliaries are controlled via miniature circuit breakers mounted on the front door. Provision is made to isolate the lock-off the generator from the grid and if required the entire panel can be isolated from the grid. The circuit breaker is of the manual close battery trip type, thus ensuring a positive means of disconnecting the generator under fault conditions if required. The circuit breaker is only tripped should a fault develop within the HWP-300 which could result in permanent damage to the aerogenerator. The main contactor is controlled by the computer and is used to synchronise the generator to the grid.

Two KW hr. meters have been incorporated into the facia of the switchgear panel. They record "KW hrs. into the grid" and "KW hrs. taken from the grid" respectively. The meters were calibrated by an independent testing authority agreeable to both parties.

The instrumentation panel houses the various transducers and relays. The transducers receive their inputs from the switchgear panel and output a 4-20mA signal to the computer for control purposes. They are mounted on DIN rail.

Mounted on the front door of the instrumentation panel are the protection relays which provide second stage protection of the system. The relays are of the induction disc type and the characteristics of these relays are well known as they can be found in almost any power station. Amond the ones used on the HWP-300 are earth fault, voltage, frequency and reverse power. A negative phase sequence current relay has also been provided.

The AVR for the generator is housed in the instrumentation panel. It is a standard device, as is all the equipment used on the HWP-300, identical to that utilised on a similar sized diesel set. The generator is run-up and synchronised on a voltage control; however, subsequent to synchronising power factor control is utilised. KVAR control may be provided if preferred.

The computer panel contains the 'brain' of the HWP-300. The computer is an industrial programmable process controller which has many hours of operation under severe conditions. It is constructed in a modular manner which allows quick fault finding and replacement. The status of each digital input (or output) is indicated by a L.E.D. on the front of each module which in turn indicates the operation of a plant mounted device e.g. a limit switch. In addition, modules are provided to interface the 4-20mA analogue inputs from the transducers in the instrumentation panel. Similarly, modules are provided to allow the computer to output analogue signals to a meter.

Provision has been made to allow the HWP-300 to be controlled manually. Switches for operation of the brakes, tips, yaw mechanism, circuit breaker and contactor are situated on the front of the computer panel. Indication of the generator r.p.m. and a synchroscope have been provided.

In addition to monitoring and controlling the aerogenerator, the computer provides a continuous output to a VDU of information relating to the machine status. Included in this display are wind speed and direction, grid volts, generator frequency, generator r.p.m., line current. Should an alarm occur, the computer will output to a dedicated printer, the time and nature of the fault and subsequent alarms.

The cables from the nacelle to the control panels in the base cone are supported at the nacelle only. They are free to twist as the nacelle rotates thus no slip rings are required. Due to the enclosed nature of the control room, tower and nacelle low smoke emission cables have been used throughout the installation. In addition, smoke detectors have been installed.

Incorporated into the design of the HWP-300 is the ability to restart automatically, provided ambient conditions are correct, after the loss of the grid connection. If the utility trips its breaker, perhaps due to a lightning strike, then the HWP-300 will shut down and will then wait until the grid has been re-established for the preset minimum time. If the grid remains stable during this period the HWP-300 will automatically go into the start-up mode.

ERECTION

The HWP-300 is designed for erection without the use of a large crane. The tower is pivoted at the base and raised to the vertical position by a winch and pulley block system (Fig. 5). The 'A' frame also pivoted at the tower base provides a moment arm for the main cable which is attached near the top of the tower.

The wind turbine complete with blades hub and low speed shaft is raised to the vertical position. With the nacelle crane rail extended to overhand the rear of the nacelle, the electric hoist is used to raise the gearbox, the generator and hydraulic panel from the ground. The erection of this first HWP-300 took place in a 15m/s wind and was achieved so satisfactorily that consideration is being given to lifting the machine complete with all nacelle components in future. The lift took approximately 30 minutes and the erection involved on average a crew of 5 for two weeks. No special provisions for transport or access were needed. The crane rail in the nacelle can also extend forward and a complete blade or tip can be lowered to the ground.

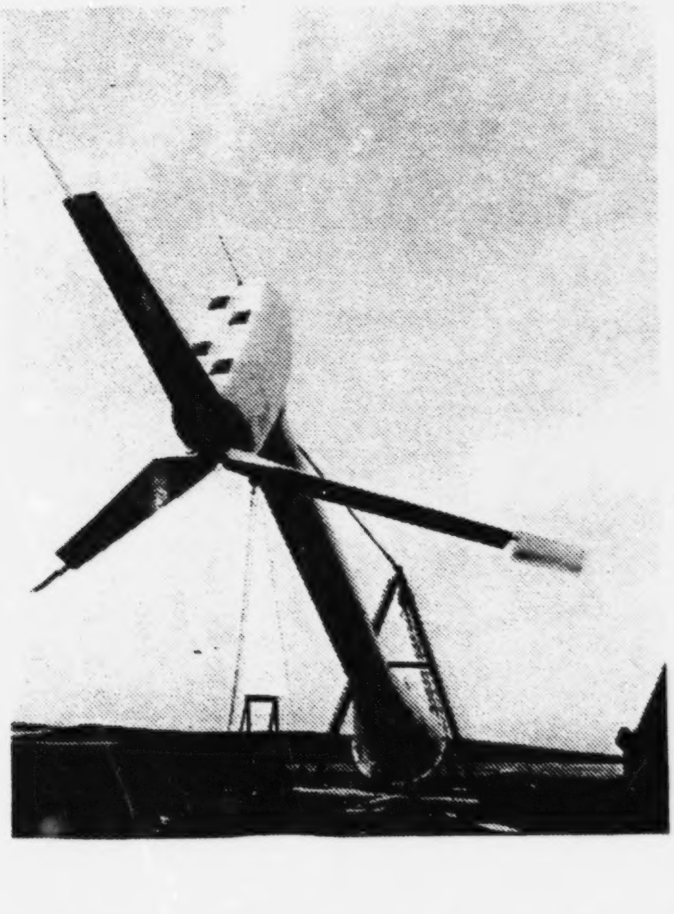


FIGURE 5 ERECTION OF THE HWP-300

ROTOR

Orientation	Upwind
Number of Blades	3
Diameter	22 metres
Blade Material	Wood/epoxy composite
Control System	Variable pitch tips
Aerofoil	GA(W) - 1
Rotor Speed	45 r.p.m.

HUB

Blade Connection	Bolted flange
Hub Type	Rigid
Diameter	800 mm
Material	S.G. Iron, BS 2789 Grade 500/7 Special

LOW SPEED SHAFT

Diameter	220 mm
Length	2145 mm
Material	Forged steel to BS 970 Pt 1 Grade 080 M36 normalised
Brake Disc Diameter	1445 mm
Disc Attachment	Bolted to integral flange on shaft

HIGH SPEED SHAFT

Diameter	70 mm
Length	1000 mm
Material	BS 970 Pt 070 M20
Coupling	Single engagement gear coupling at each end
Coupling Lubrication	Grease

GENERATOR

Type	Synchronous
Phase	3 phase, 4 wire
Voltage	415 V
Rating	420 kVa
Insulation	Class F
Temperature	80° above 40°C ambient
Power Factor	0.8
Speed	1500
Frequency	50 Hz
Enclosure	Drip proof IP 21
Cooling	Fan
Bearing	2 ball bearing type grease lubrication

HYDRAULIC CONTROL SYSTEM

Maximum System Pressure	160 bar
Brake and Blade Tip Control Valves	Solenoid actuated and spring released
Yaw Motor Control Valves	2-way solenoid actuated
Pump Motor	5.5 kW, 3 phase, induction
Pump Type	Gear, 14 litre/minute capacity
Acumulator Capacity	4 litre
Reservoir Capacity	100 litre
Fluid Type	Mineral Oil

LOW SPEED SHAFT DISC BRAKE

Type	Spring applied, hydraulic release
Emergency Brake Torque	130 kNm
Normal Brake Torque	50 kNm

YAW SYSTEM

Bearing	2.2 metre diameter crossed roller type with internal gear
Lubrication	Grease
Rate	0.2 r.p.m.
Drive System	Twin low speed high torque axial piston motors
Brake	1.8 metre diameter disc with three dual action spring applied hydraulic release calipers

CONTROL SYSTEM

Type	Industrial programmable process controller
Inout/Output Modukes	Plug-in, optically isolated
Information Display	Printer and V.D.U.
Control and Switchgear Enclosures	Ingress Protection to IP54
Design Standard	British Electricity Supply Industry Standard 50-18

BEDPLATE

Construction	Welded
Material	Steel plate BS 4360 Grade 43A Hot rolled section BS 4360 Grade 43C
Nacelle	Glass reinforced plastic shell

TOWER

Diameter	1820 mm
Height	22 metres
Access	Internal ladder
Material	BS 4360 Grade 43A

PERFORMANCE

Maximum Power	300 kW
Wind Speed at Hub Centre Line	
Cut in	5 m/s
Cut out	24 m/s
Design	67 m/s
Survival	94 m/s

SYSTEM WEIGHTS

Blade	335 kg
Hub	870 kg
Complete Rotor	2205 kg
Nacelle	14700 kg
Tower	22370 kg
Total System	39275 kg

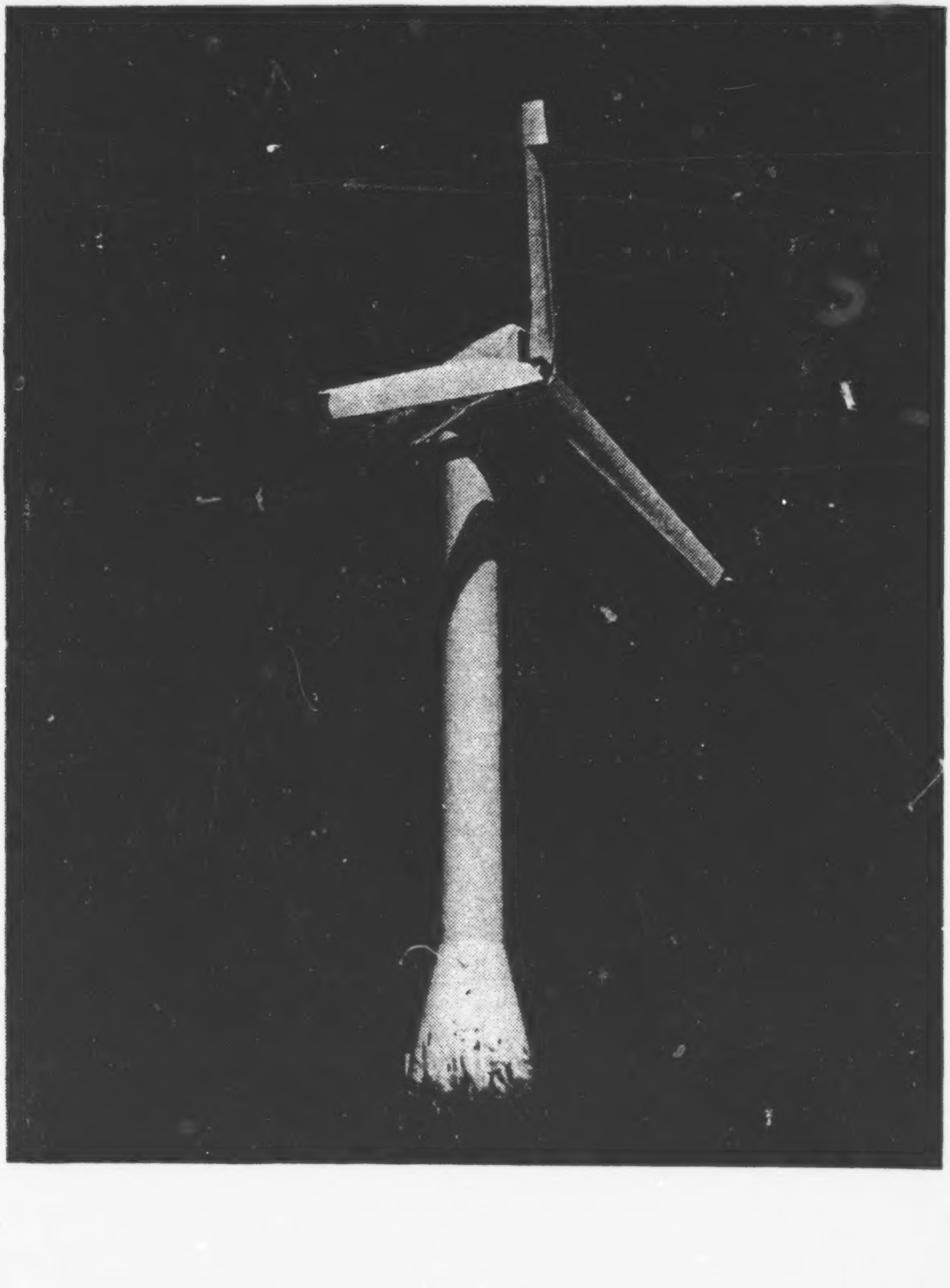


FIGURE 1 HWP-300, BURGAR HILL, ORKNEY.

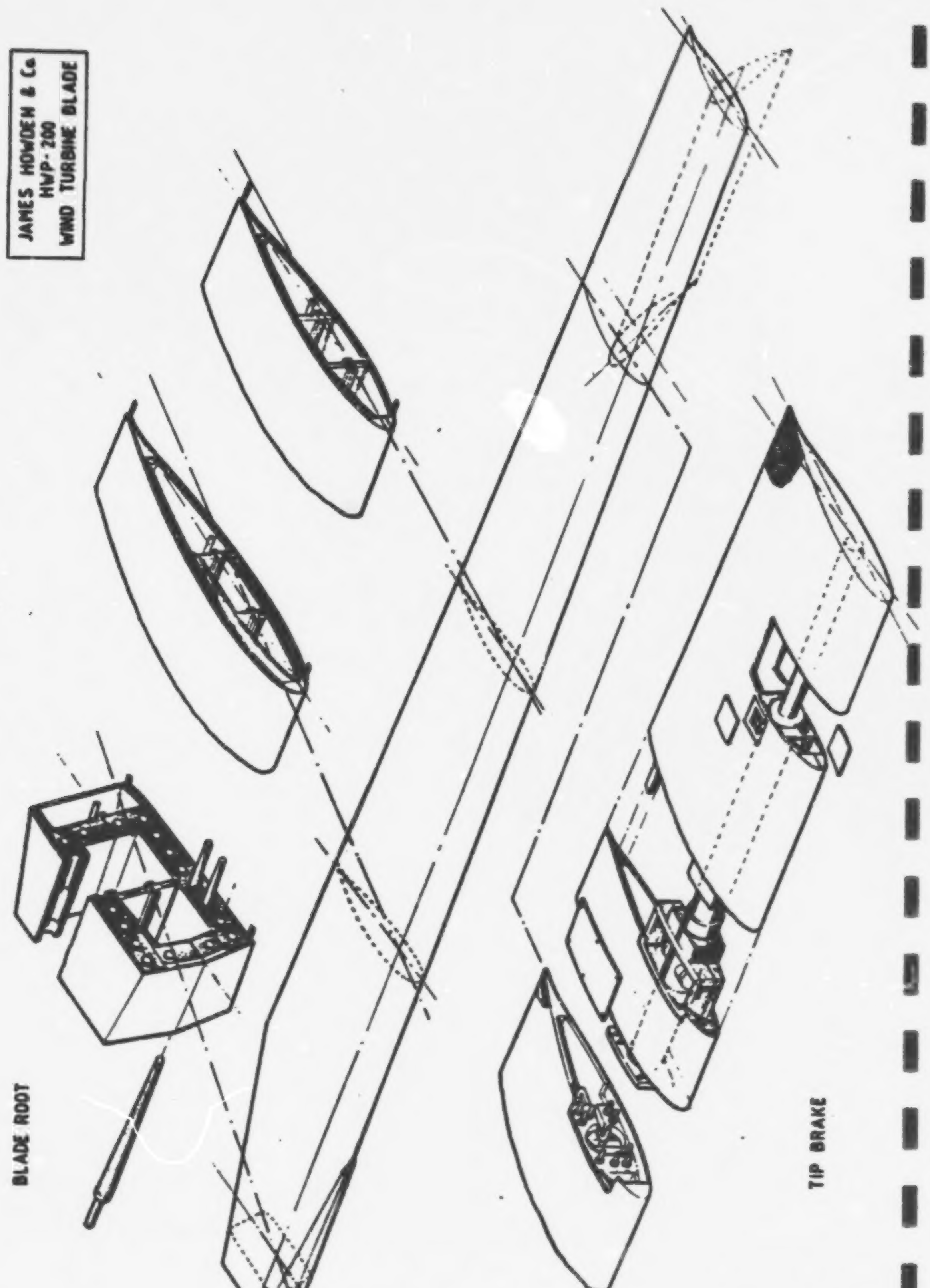

JAMES HOWDEN & Co.
HWP-200
WIND TURBINE BLADE
BLADE ROOT
TIP BRAKE

FIGURE 2 BLADE CONSTRUCTION

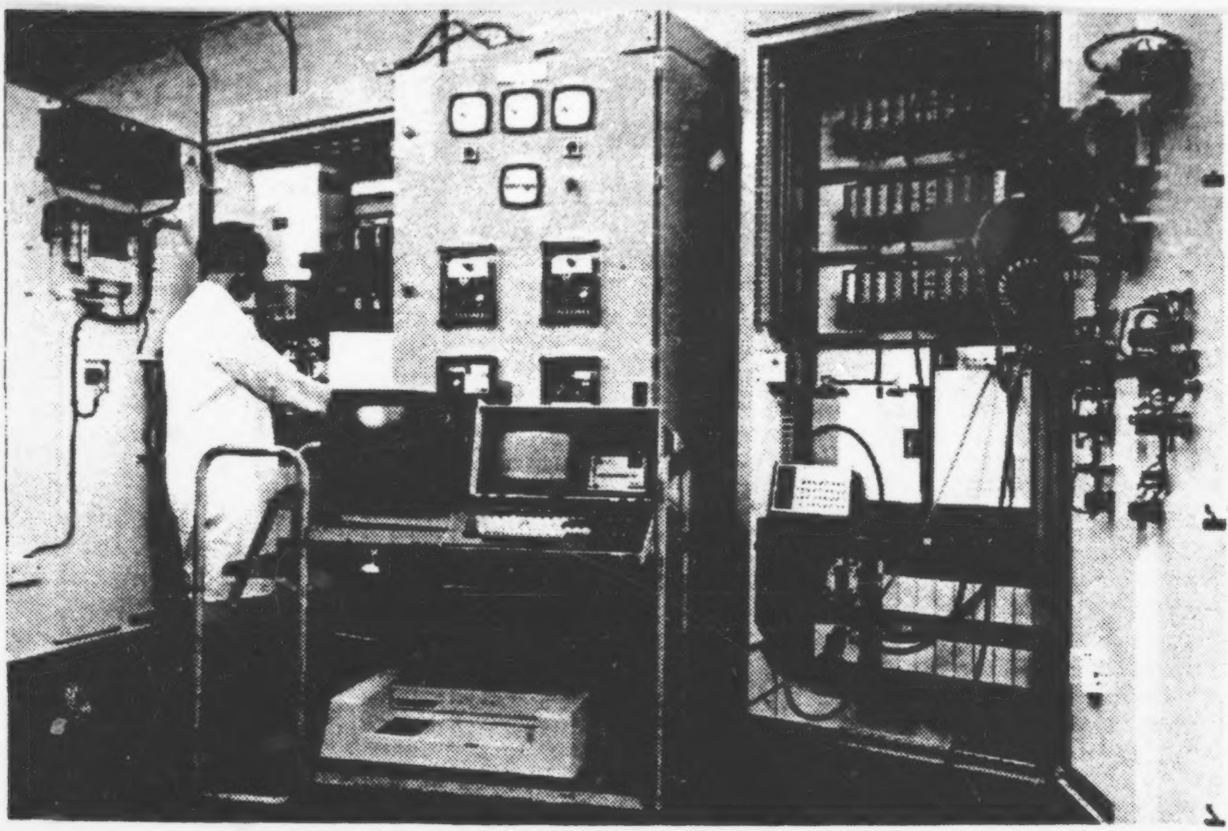


FIGURE 3 ELECTRIC CONTROL PANELS

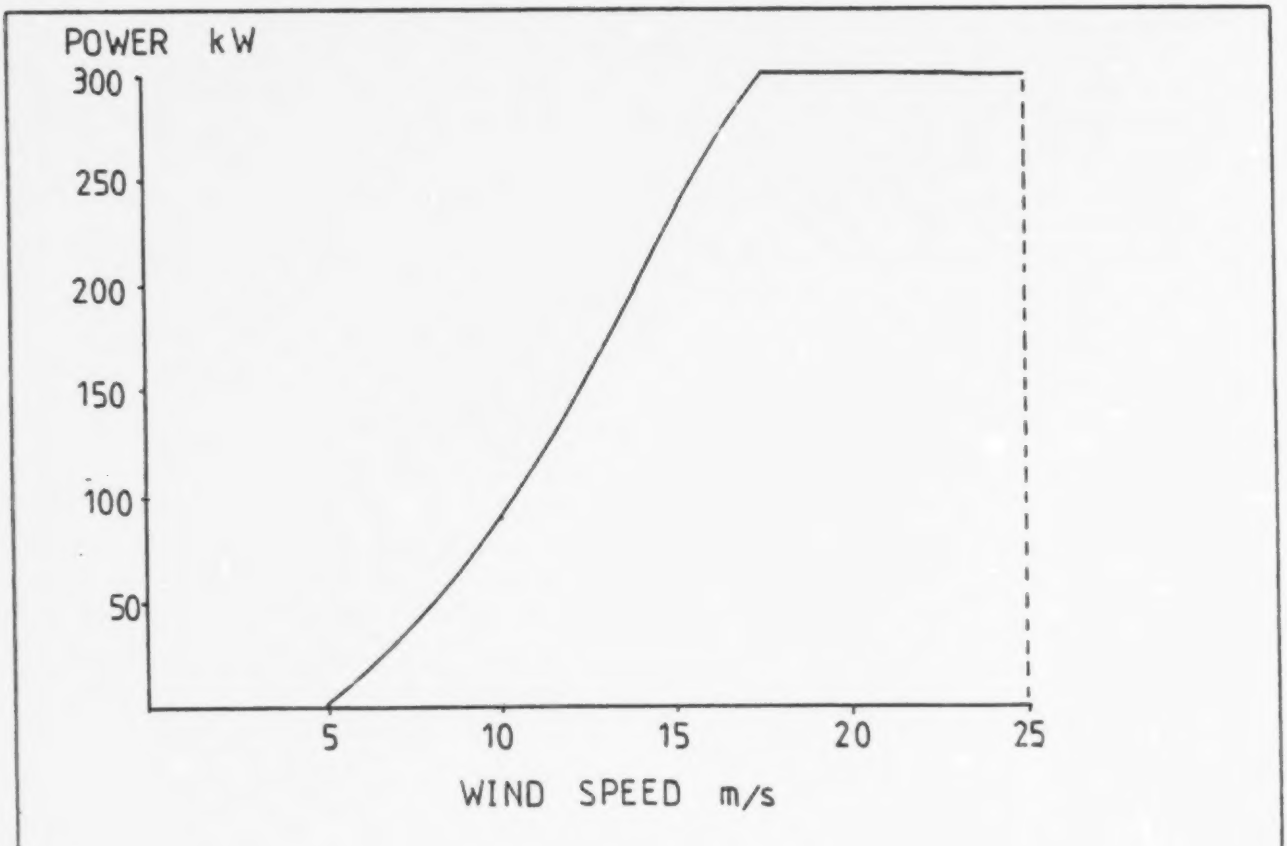


FIGURE 4 HWP-300 PREDICTED POWER OUTPUT

RANDOMNESS OF THE WIND SHEAR COEFFICIENT IN COMPLEX TERRAIN TO A HEIGHT OF 450 FEET

Frank Kaminsky, Phd., Department of Industrial Engineering and
Operations Research
Robert H. Kirchoff, Phd., Department of Mechanical Engineering
University of Massachusetts

I am going to change the tone of the conference. I am not going to talk about hardware I'll talk about meteorology.

Approximately 5 years ago, one of the major utilities, Northeast Utilities in Connecticut, came to the University of Massachusetts and asked if we could do a wind prospecting study for both the states of Connecticut and Massachusetts. At that time it was somewhat progressive on the part of a utility to feel that they should be doing something like this. They felt they would like to get a solid database on which they could make some economic analyses of the potential for wind energy in both Connecticut and Massachusetts.

(SLIDES)

Our task was to take the western part of Massachusetts, which is in this region of figure 1, and the northwestern part of Connecticut, and tell Northeast Utilities where they could establish a wind energy system. In addition, they wanted us to take a look at commercially available systems, to simulate the behavior of these systems, then come up with an economic analysis of wind power for a major utility.

We have been working on this study for the past four years. This summer we submitted a final report of a three-phase research project to Northeast Utilities. The basic conclusion of all of this is that the Utility is not ready at this particular point to invest in wind power in both Connecticut and in Massachusetts. They are interested in working with people to put in wind systems, generate electricity and tie into their grid. They feel at this particular point that the equipment that is available on the market right now is not such that they could justify economically the output of the system, so they are holding off.

However, they are at least in a position now to have three years of data at numerous sites. For example, in Windsor Massachusetts, Brodie Mountain, Massachusetts, and two sites in Connecticut, we have been collecting data for approximately three years. We have the average wind speed and the wind direction for every 15 minute interval. We have all that stored on tape and have already processed the data. We have also instrumented several other sites. So we have a fairly substantial database.

The original approach was to take the large region and to use biological wind prospecting to narrow the large region down into a number of sites that we felt were developable from the point of view of wind power. What we decided to do was to take the biological study and then use a computer program called MATHEW, which is a mass consistent model, to give us a three-dimensional wind field for particular sites. We very quickly realized that it was going to take us approximately two years to get the program operational on the University of Massachusetts system. So we immediately moved into the final step which was instrumenting particular sites.

Even though this is not part of my talk I am going to be taking one of these sites. For example, from this particular site, which is in this part of Massachusetts, I am going to show you some data we collected on how wind increases with height. It became a very important database for our estimates of energy.

Now, in our biological study, we apply the Griggs-Putnam Index (Figure 2), which relates tree deformation, particularly conifers, to the range of average annual wind speeds. In many places in both Connecticut and Massachusetts we are in Class IV. In some places we have seen trees that were completely thrown from the base which tells us that we are in the 16 - 21.7 mph average. Most of the sites are in the Class III to Class V range. Some of the selected sites are in this range 14 - 19 mph.

There are good sites. The real problem initially was that most of the good sites were totally inaccessible, even though we could photograph the trees. We had to settle on some sites that were more accessible and better from the utility point of view.

To give you an example of some of the biological indicators in northwestern Connecticut, which is not generally considered to be a very good wind site, you can see these trees here. As a matter of fact in this region the entire hillside is completely stripped. All of the conifers, all of the pine, all the hemlock and some of the spruce in the area are completely stripped and deformed. You know that is a good wind area.

In Windsor, Massachusetts we selected this particular site to do our wind shear studies. At this particular site we are going to examine how wind is increasing with height.

Since my talk deals with complex terrain, Figure 3 shows the kind of terrain that I am talking about. For example, if you slice the hill top at Windsor from north to south, this is what the terrain would look like. If the wind were coming from the north it would have to go up over this ridge. Also, if the wind were coming from the northwest. In most cases in Massachusetts and Connecticut, strong energy winds are coming from the west to the northwest quadrant. Regardless of the wind direction, the terrain can be considered fairly complex. The site of our anemometer was at the highest point in this terrain. Our anemometer was located at 65 feet above ground level. We were recording the average wind speed and average wind direction every 15 minutes. We have compiled a solid database over four years..

Again, what we are doing is looking at the manner at which wind speed increases with height. Meteorological theory says that as you go up, the wind increases with height. It is important to point out that you have to talk about the average wind speed over some fixed interval of time. If I give you the average wind speed at this particular height over a fifteen minute interval, the wind shear that we are talking about is the average wind speed at a second height over the same interval of time. Wind shear and an interval of time both go hand in hand.

The Windsor site is not a particularly good site from the point of view of annual average wind speed. Table 2 is contains one year's worth of data for both 1981 and 1982. You can see we are dealing with a 13.5 mph site at 65 feet above ground level. The distribution of the winds are typical Rayleigh or Weibull distributions. We have the statistical summaries for every month, and for every month the same type of model is appropriate.

When I talk about wind shear I am talking about the power law profile. In other words, this relationship here is the relationship that I am talking about. 'Alpha' is the wind shear coefficient. Typically, if you have two data-points, for example, a 15 minute interval and the average wind at 60 feet above ground level, to get the average wind at 100 feet above ground level then this is the equation you use to compute the wind shear coefficient.

In our studies we used the existing anemometer but we also used TALA kite anemometers. We would fly several of these kite anemometers. This is what it looks like. It is a simple airfoil. At the base you have a Kevlar line with zero stretch and a fishing reel with a tube on it that is calibrated so you can read the instantaneous wind speed. We can fly these kites easily up to 500 feet - 800 feet without any difficulty at all which doesn't necessarily mean we never have any problems.

This is one of the research students sighting the kite. As you record the wind speed you take a sighting on the angle at which the kite is off the ground which helps you to get the true altitude of the kite. We would sample the wind speed every ten seconds. We would do this for fifteen minute intervals at a time.

At the Windsor site we made 173 different kite flights. We were using the existing anemometer plus two or three additional kites. We were getting a very good handle on what the wind shear was, up to a reasonable altitude.

This is Frank Kaminsky in a tree trying to retrieve one of the kites. That was what I was talking about, professors don't always sit behind their desks.

One of the things that we did was to take some work of Garstang, who worked in Wallops Island, Va., which related wind shear over flat terrain to something called synoptic weather categories. These are large scale weather systems that move in. Figure 4 identifies approximately five different large scale synoptic weather categories. In other words, you can go to the US daily surface weather maps that are produced at 7 a.m. every morning, and by looking at the surface weather maps you can determine, say, that synoptic weather category 2 is in effect today. Each day you can determine which synoptic weather category is in effect.

What we were trying to do was show how wind shear might change with each synoptic weather category. We developed the very simple chart shown in Table 2 that would help us analyse the daily surface weather maps and tell us which synoptic weather category was in effect. For example, if you are behind a cold front, if you have a cyclonic isobaric pattern, and a number of different characteristics you can tell which category you are in. In New England, particularly in the area we are in, we use the weather maps every 7 o'clock in the morning. These are actually produced every three hours, so you can determine at three hour intervals what synoptic weather category was in effect.

During our period of study which was in the year 1980-81 we looked at the surface weather maps every morning for the entire year. I don't have all the data here but this gives you some idea of the percentage of time or the percentage of days in the year when we you have each synoptic weather category in effect. In our area synoptic weather categories three and four occur most frequently.

Category four, for example, is where a cold front moves through and the winds switch around to the northwest. You start getting some good energy winds.

Category five is one where you have a Bermuda high sitting off the coast of New England, pumping the hot air up into New England. It occurs quite frequently, most of the time in the summer.

From figure 6, for 173 different kite flights we made, we measured the wind shear coefficent over a fifteen minute interval of time. For the distribution that we obtained, you can see the variability in the wind shear coefficient. We were getting wind shear coefficients from minus .3 all the way up to plus .6. The average wind shear coefficient, which occurs in here, is .233. Typically, in the past at least, people have been using 1/7th as the wind shear coefficient. In the complex terrain that we have been looking at we were getting a much higher wind shear coefficient of .233. That has a significant effect on the energy that you are going to get from a wind machine, particularly if you are projecting the wind speeds up to a height of 90 meters or more and you are collecting your data at 20 meters.

One begins by breaking down the data into synoptic weather categories. For example, figure 5 shows all those data that were collected during synoptic weather category one. If you plot a histogram of this data you'll see a much higher average wind shear coefficient in synoptic category one. If you go to synoptic weather category three, you'll see again a difference, a complete difference in the wind shear coefficient, i.e., .186. For synoptic weather category four, you'll find that .155 is the wind shear coefficient. We didn't have enough data to get synoptic weather category two. So, there are some basic flaws in our overall picture.

If you plot these and put a 95% confidence interval on the wind shear coefficient, what you see is that in synoptic weather category one you have the highest wind shear coefficent. Typically, there is a decrease in the wind shear coefficient as a function of the synoptic weather category.

This is identical to the results that Garstang obtained in the flat terrain in Wallops Island, Va. The only difference is that his whole curve was shifted down compared to our curve.

The overall purpose of conducting this study was to create a computer simulation model so that we could get a better handle on what the distribution of energy would be from a particular machine. We have developed a mathematical model that describes probabilistically how synoptic weather categories change over time. Then, using this probability model and a computer simulation, we can randomly pick a synoptic weather category, randomly determine a length of time, randomly pick a wind shear coefficient, raise wind speeds from a measured to a projected point, compute energy and go like this for an entire year. We can then obtain a distribution of energy for a year.

The study here is not actually completed. We would love to have three hour intervals on synoptic weather categories. We would love to have much more data on the wind shear coefficients. But, at this point, we don't have the funds to continue this research.

I will answer any questions.

Q. What effect does height have in terms of wind shear for horizontal and vertical axis machines?

A. If you are talking about a horizontal axis machine that has a large rotor diameter, for example, the MOD-5B with about a 400 foot rotor diameter, then you have a serious change in wind velocity across the surface area of the blades. We have actually run some computer simulation studies to try to show the effect of the changing wind speed across the wind swept area. It turns out that if you use the wind shear coefficient similar to what we have computed and then you compute the wind speed at hub height to get the energy, that is not bad at all, if you have a nice looking wind shear pattern. The problem is, when you plot wind shear you get a lot of strange looking wind shear patterns where you get almost separation of flow at 65 feet versus 300 feet. You will actually decrease in wind speed and your energy estimates are off by quite a bit. But typically, if you just take an average wind shear coefficient, adjust the wind speed to hub height and use hub height to get the energy across the swept area - it's fairly accurate.

Q. Have you had the opportunity to correlate your data with long term data from nearby weather stations?

A. We have correlated our data with some long term weather stations. Our problem is the weather stations are at airports, typically very low wind speed areas. In New England, and particularly, in Massachusetts and Connecticut you would have to go to Hartford, Connecticut or Albany, New York to get any long term data whatsoever. They are both in extremely low wind areas. We are talking about an annual wind speed of 7.5 mph versus 14 - 15 in some of the areas in New England.

Q. You have attempted to do this?

A. We have correlated some of our data stations which are separated by as much as 80 miles. We have gotten fairly good correlations. I think that the basic rule of thumb in New England is: when the wind is blowing and you are up on any peak in New England, you are going to get essentially the winds that are distributed across the entire region. That is why many people believe that if you put a wind system up at 500 feet above ground level in New England and western Massachusetts and western Connecticut you are going to generate energy, substantial amounts of energy.

Q. Can you explain your instances of negative wind shear coefficients?

A. No. We did look carefully at all of the negative wind shear coefficients. We looked at the contours of the land. We tried to relate these negative wind shear coefficients to particular wind directions. We had no luck whatsoever in doing any of that. We may have been looking at just the inaccuracies of the recording equipment more than anything else. But we also, spent a lot of time calibrating our equipment and checking our kite anemometers against other anemometers. All our anemometers are calibrated in wind tunnels, so we felt fairly good about our data. But we had no explanation why we were getting these negative wind shear coefficients. We also looked at wind shear over 15 minute intervals, wind shear over half hour intervals, 1 hour intervals, two hour intervals, and using other sets of data. We still get some negative wind shear coefficients.

Q. Were you measuring wind shear coefficient at only two levels?

A. No - actually the equation I showed you would be the way you'd compute wind shear using two levels. We were flying kites at three levels and we were also using the existing anemomter. We were measuring 65 feet, and we were approximately 150 feet, about 300 feet, and 450 feet. So we were getting a good spread across the wind profile.

Q. Did you examine the correlation between the weather categories and the wind shear values and the local weather station data?

A. Yes - You mean the individual wind shear values - yes, we looked at all the individual wind shear values, plotted each one of them and tried to relate those to the individual synoptic weather categories also.

Q. What in your opinion is a 'nice' wind shear coefficient for large diameter machines like MOD-5B and projet EOLE?

A. If you are in New England and you are on top of fairly rugged terrain. We typically use .21 as our wind shear coefficient - .2 to .23. We have also taken data at a number of other sites where we get the same kind of variability. You can walk up to a site, weather conditions identical to the last time you went up there, fly your kites at three different levels, come home, compute the wind shear coefficient and get a completely different value. What we are really trying to say is that the wind shear coefficient is a random variable, it cannot be used in a deterministic model. I think we have to start treating it as a random phenomenon.

Q. But in your opinion, what wind shear coefficient is acceptable for large diameter machines in terms of the loading differential across the rotor diameter? Are you talking at the low end .1 some odd or what?

A. We are talking about the height at which you collect data, then we are looking at the hub height of the wind system. We are changing the height at which you collect data, to the hub height, using a wind shear coefficient of .21 - .23, in that region. The previous talk mentioned the estimate of energy at 90 meters above the ground level. If you were using a wind shear coefficient of .21 instead of 1/7th in that particular case, you would see a tremendous difference in watts/square meter.

Q. How were temperature and air density incorporated into your values?

A. We made temperature and air density corrections for the kite flights. In order to get the true wind speed we had to make temperature and air density corrrections. But, in terms of, computing a wind shear coefficient for a particular flight, no we did not make adjustments. The adjustments were just made in computing the true wind speed based on the numbers that we recorded from the kites. We have a line count, we have an angle off the ground and a caternary equation to compute the height of the kite above ground level. The adjustments have to be made there for density and temperature.

Q. Was an attempt made to measure the stability of the weather categories?

A. The purpose of the synoptic categories is to try to collapse the many stability categories into five fairly simple categories which can be read easily from the surface weather maps each morning or each three hour interval. The stability categories are actually built into the synoptic weather categories.

Q. Under such an analysis might the wind shear correlationship appear less random?

A. I have actually seen some other work that looked at stability categories and wind shear coefficients. In those studies there was randomness too. I did not compare their variability to the variability that we were seeing. But there was randomness.

Q. Is there a correlation between the changes in wind direction with synoptic weather categories that has any bearing on wind shear coefficient?

A. Correct, you would expect that when the synoptic weather category changed you would get a change in wind direction and profile. We tried to relate topographical profile to wind shear coefficient. We could not get any significant relationship between the profiles that we were seeing and the wind shear coefficient. In fact, we were getting completely the opposite. You would speculate that the wind shear coefficient would be highest from a particular direction. You go dig all the data out and look at it - it is not the case. I think in general, there is a relationship. If you look at some extreme topographic situations, I think you could generally say that the wind shear coefficient is going to be higher in those situations.

Thank you.

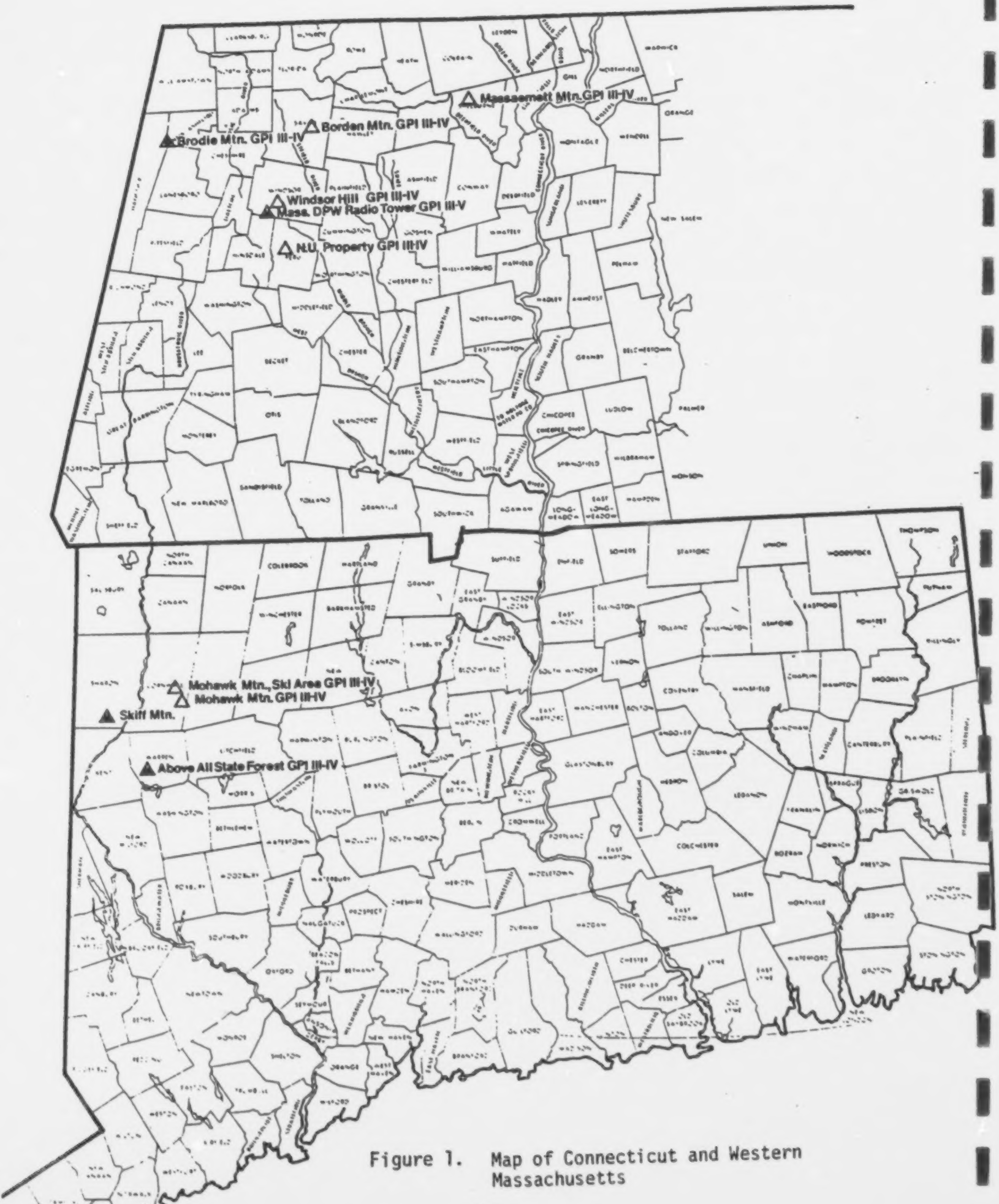

Massamett Mtn. GPI III-IV
Borden Mtn. GPI III-IV
Brodie Mtn. GPI III-IV
Windsor Hill GPI III-IV
Mass. DPW Radio Tower GPI III-V
N.U. Property GPI III-IV
Mohawk Mtn., Ski Area GPI III-IV
Mohawk Mtn. GPI III-IV
Skiff Mtn.
Above All State Forest GPI III-IV

Figure 1. Map of Connecticut and Western Massachusetts

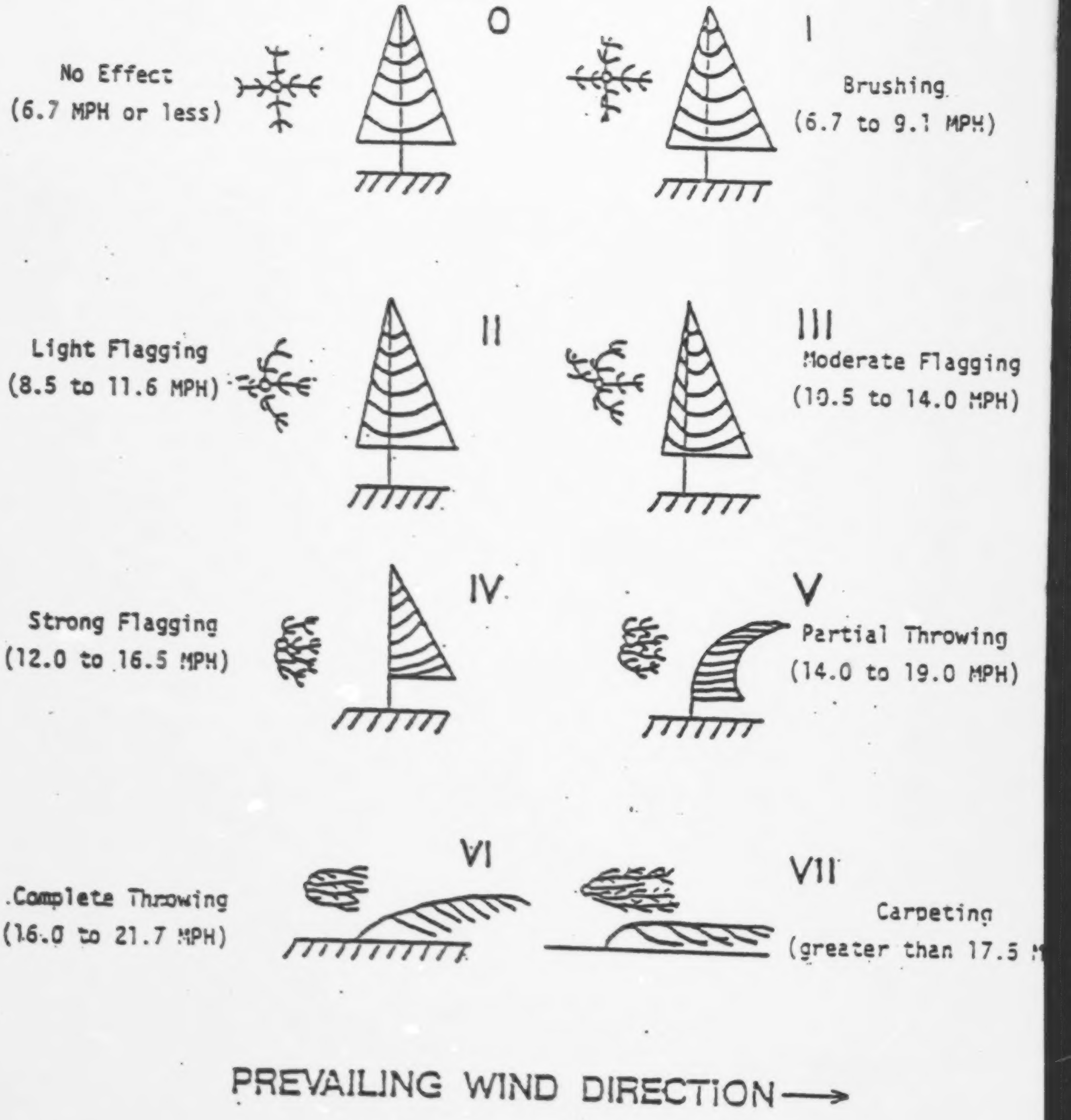

0
No Effect
(6.7 MPH or less)
I
Brushing
(6.7 to 9.1 MPH)
II
Light Flagging
(8.5 to 11.6 MPH)
III
Moderate Flagging
(10.5 to 14.0 MPH)
IV
Strong Flagging
(12.0 to 16.5 MPH)
V
Partial Throwing
(14.0 to 19.0 MPH)
VI
Complete Throwing
(16.0 to 21.7 MPH)
VII
Carpeting
(greater than 17.5
PREVAILING WIND DIRECTION →

Figure 2. Griggs Putnam Index

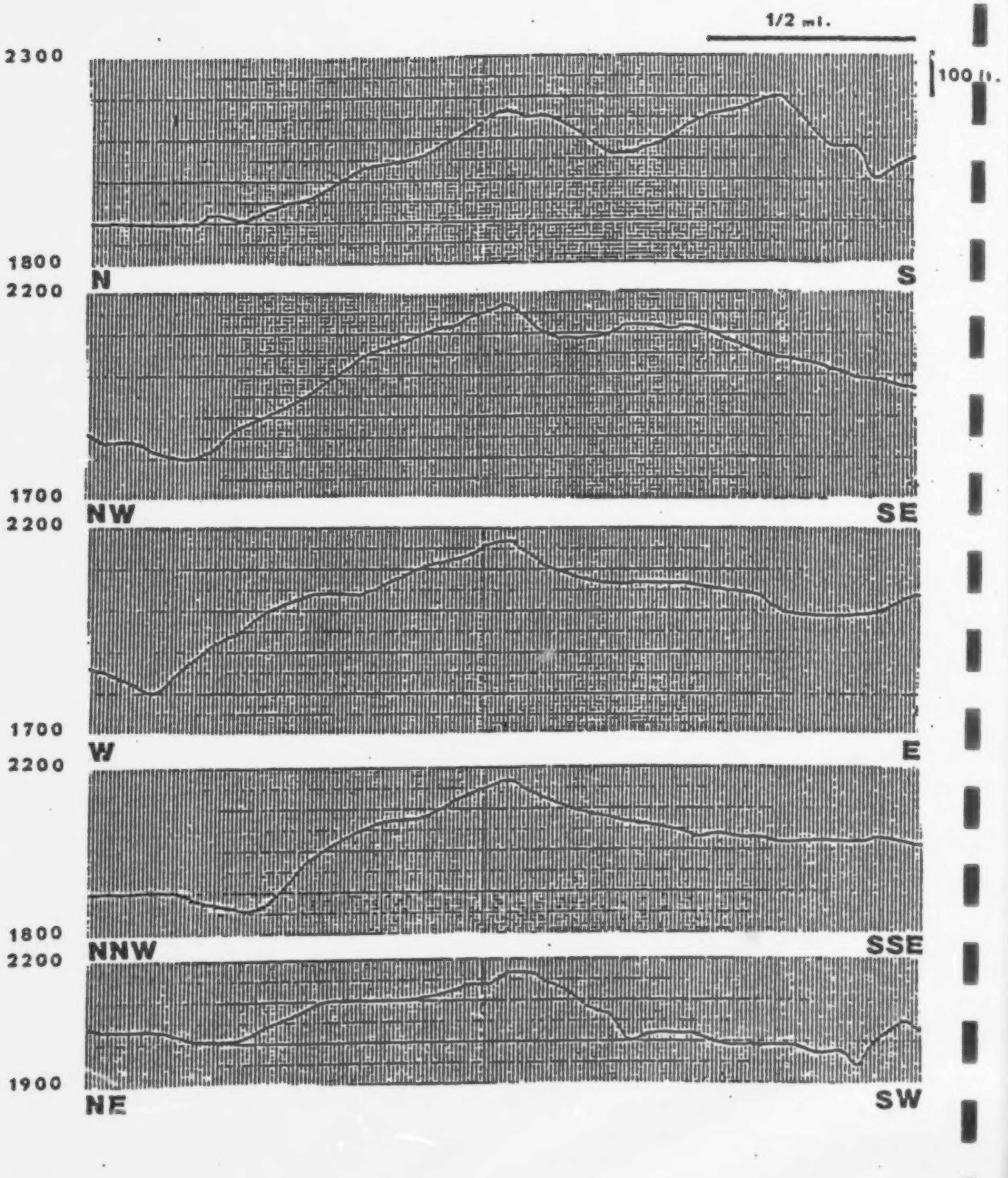


Figure 3. Terrain at Windsor, Massachusetts

Table 1

Summary of Wind Speed Data
DPW Tower - Windsor, Massachusetts

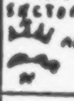
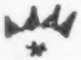
	Year					
	1980		1981		1982	
Month	Average (mph)	Standard Deviation (mph)	Average (mph)	Standard Deviation (mph)	Average (mph)	Standard Deviation (mph)
January			15.27	7.69	14.84	6.24
February			15.28	5.67	13.55	6.19
March			14.07	6.04	13.73	7.03
April			15.35	5.93	16.91	7.84
May			14.29	6.13	10.55	5.35
June			14.05	6.62	11.84	6.35
July			11.05	4.17	10.45	3.34
August			9.22	2.85	9.94	3.45
September			12.13	5.14	10.07	3.52
October	13.92	5.80	12.22	4.55	11.01	3.94
November	14.08	5.71	14.73	6.14	14.21	5.47
December	15.14	7.49	14.63	7.63	12.26	5.09
Annual	--	--	13.52	5.71	12.45	5.32

Figure 4. Synoptic Weather Categories (SWC)

Category	Description
I	In the warm section, i.e., ahead of the cold front, and/or behind the warm front. Generally a straight isobaric pattern. Air mass is maritime tropical (MT).
II	Ahead of the warm region with cyclonic curvature of isobars. The air mass is maritime polar, continental polar or continental arctic with maritime tropical above ($MT/_{MP}$, $MT/_{CP}$, $MT/_{CA}$).
III	Behind the cold front in the region of cyclonic curvature of isobars. The air mass is continental polar or continental arctic (CP, CA).
IV	Under a continental polar or arctic high with anticyclonic curvature of the isobars. The air mass is continental polar or continental arctic (CP, CA).
V	In the vicinity of the subtropical ridge with anticyclonic curvature of the isobars. The air mass is maritime tropical (MT).

DATE: ______________

SYNOPTIC WEATHER CATEGORY: ______________

SYNOPTIC WEATHER CATEGORY	ISOBARIC PATTERN	UPPER LEVEL RIDGE/TROUGH	FRONTS	AIR MASS	ΔP	$T-T_D$	CLOUD %/TYPE	PRECIP.	COMMENTS
I	STRAIGHT	RIDGE	WARM SECTOR  and/or	mT	↗ ↘	HIGH HUMIDITY ↓	> 70 Ac, dAc, Ci, Cb	SHOWERS NEAR FRONT, FOG	
II	CYCLONIC Ⓛ			$\frac{mT}{mP}$, $\frac{mT}{cP}$, $\frac{mT}{cA}$	↓	↓	> 90 St NEAR FRONT As NORTH OF FRONT	CONT. RAIN OR SNOW	
III	CYCLONIC Ⓛ	TROUGH		cP, cA	↑	↑	> 60 Ac, dAc	INTER-MITTANT HEAVY AT TIMES	
IV	ANTI-CYCLONIC Ⓗ	TROUGH		cP, cA	→ ↗	↗ ↘	< 50 Cu, Ac AFTER COLD FRONT	LIGHT TO NONE	
V	ANTI-CYCLONIC Ⓗ	NEAR SUB-TROPICAL RIDGE		mT	↙ →	↓	< 50 Ci, Cb	SHOWERS	
VI	CLOSED ISOBARIC PATTERN	UNDER SUB-TROPICAL RIDGE		mT	↙ →	↓ HIGH HUMIDITY	< 50 Ci, Cb	SHOWERS	

____
ANALYST

Table 2. Synoptic weather category worksheet.

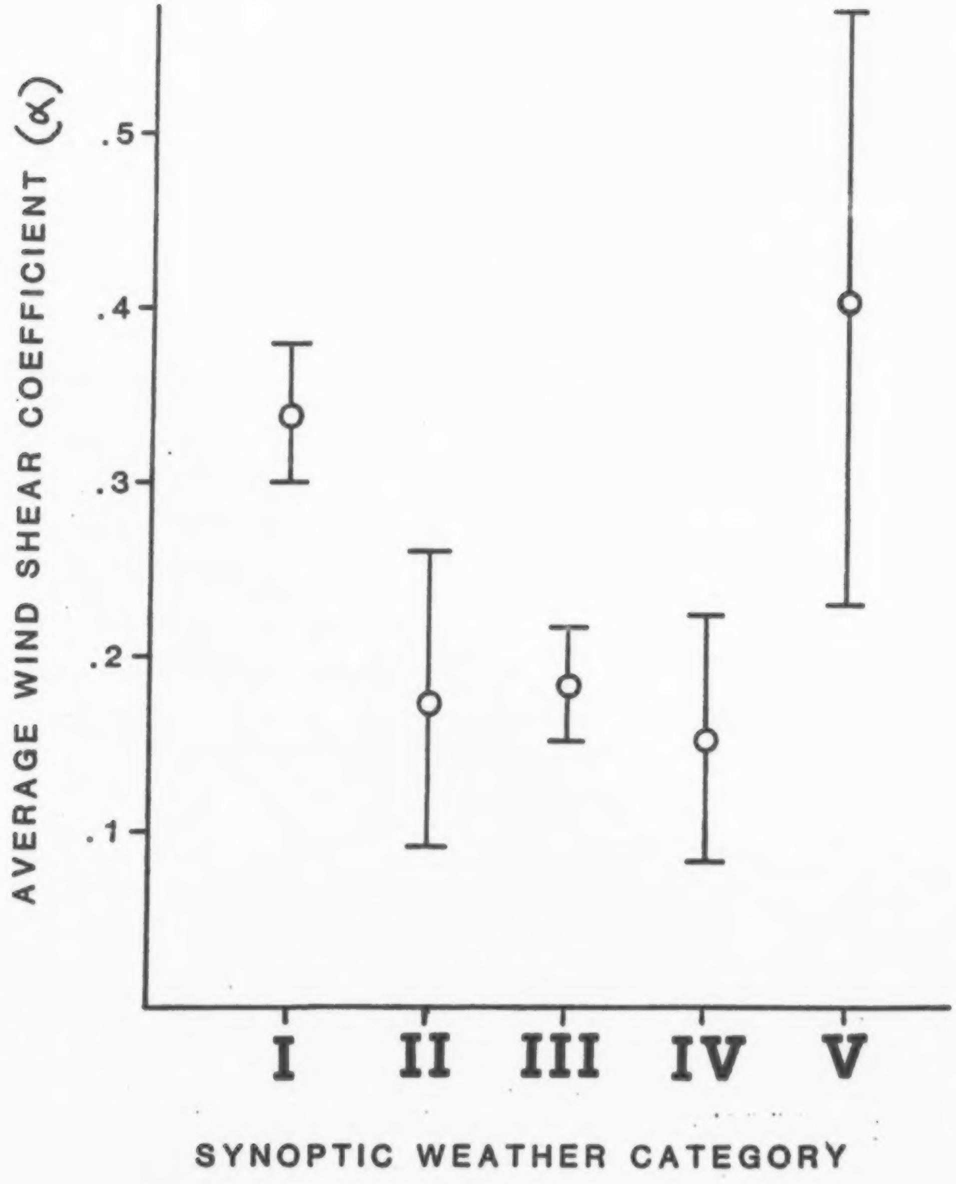


Figure 5. Wind Shear vs. Synoptic Weather Category

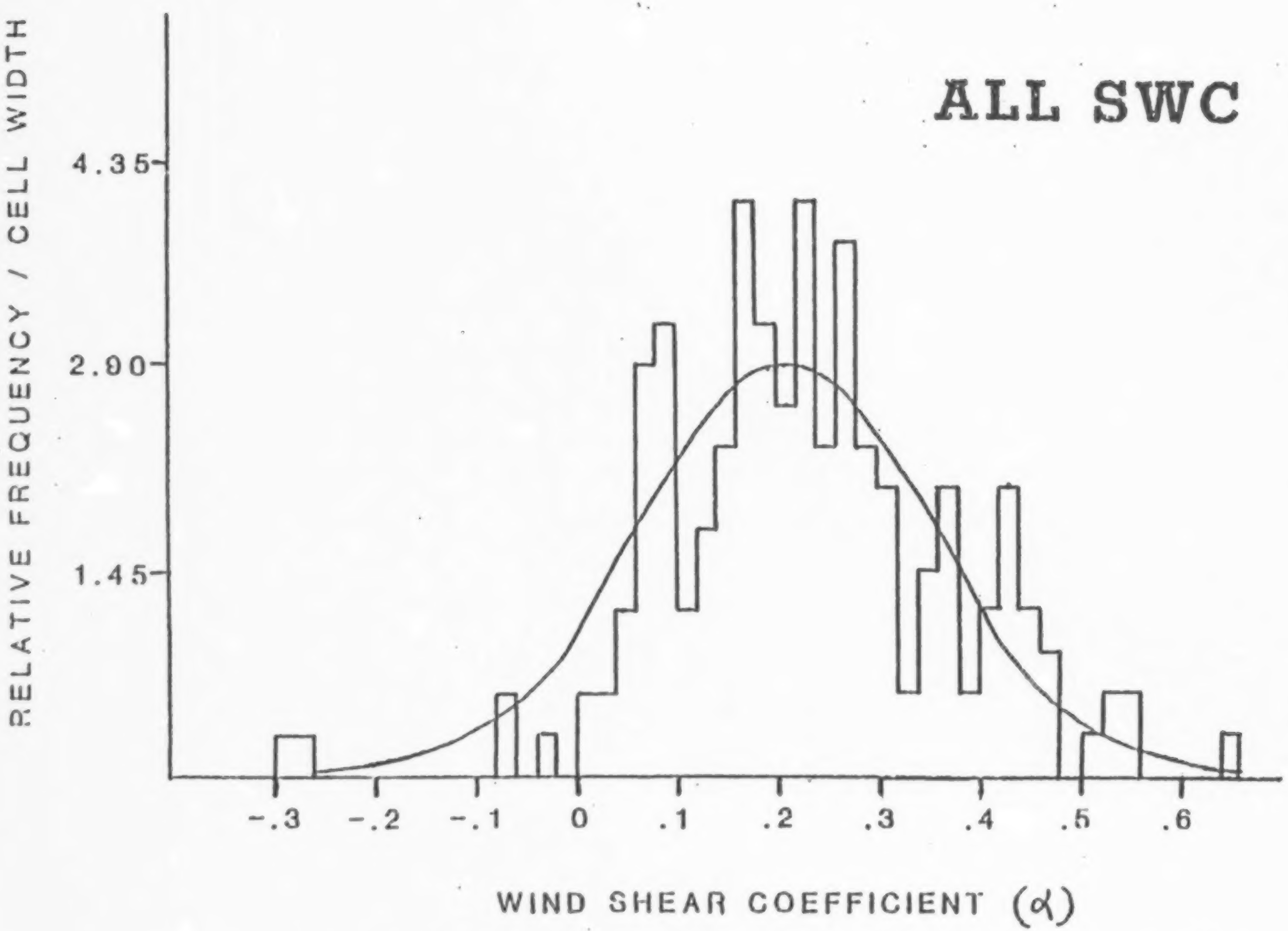


Figure 6. Relative Frequency Divided by Cell Width versus Wind Shear Coefficient

"INTERSOL 1985"

Marc Chappell,
National Research Council

At this point I would like to introduce Marc Chappell of the National Research Council. He has an announcement to make.

Thank you, Fred. I have only just a couple of things to mention. I would like to in fact give three acknowledgements.

First one, to Nicholas Teekman for an absolutely fantastic job of arranging the meeting, the speakers, and the lunch which was excellent.

The second acknowlegement I would like to make is to Saeed Quraeshi as the only speaker who managed to come prepared with a full set of view graphs to answer all possible questions.

And the third accolade I would like to give is to Marvin Bedward, who is the only civil servant I know of who publically admitted that his department reduced the entire country to 'tears'.

The announcement on a serious vein I would like to make is concerning Intersol '85. This is the international meeting held once every two years sponsored by the International Solar Energy Society.

You must recall that solar energy in most communities is concerned with the broader aspect of all solar, so wind falls under solar. Even though in Canada we tend to regard the use of the word solar to mean predominantly the radiant type.

This meeting, held every two years, has approximately 400 to 500 delegates from somewhere between 30 to 50 countries. This year the meeting is held in Perth. That is the interesting Perth, not the one up by Ottawa, but in Australia. In 1985 it will be held in Montreal.

The dates, so you can mark your calendars early, are the 23rd to the 29th of June and will be held in the Palais d'Congress in downtown Montreal.

The theme of the conference is 'Solar Energy the Diverse Solution'. The organizing team in trying to address this theme are particularly desirous of getting a variety of what we call 'renewable energy resource' type papers and sessions.

Mr. S. Engstrom of Sweden and myself have been asked to organize the wind energy part of the activities. So we would be interested in your comments and of course eventually in your participation in the meeting in either the form as a speaker or at least as an attendee.

So remember then Intersol '85. Do consider contributing or at least coming along and attending what will be a very major technical meeting coupled with a world class exhibition. Thank you for your time.

FUTURE DIRECTIONS FOR WIND ENERGY DEVELOPMENT

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ABSTRACT

A proposal for future wind energy development planning based on a review of previous successful technologies and a consideration of the reasons for their success.

THE NEED FOR LONG TERM PLANS IN THE WIND INDUSTRY

The use of wind energy today is something of a paradox: although wind energy has been with us since the time of the ancient Persians, the requirements which now exist for the effective use of this energy resource are such that an entirely new technology must be developed. These new requirements define a very broad spectrum of concomitant design considerations which include the social and legal aspects in addition to the engineering concepts. The ancient windmill designers had one very simple requirement: did the windmill function reliably? By contrast, the modern wind turbines have a multitude of design requirements that must be worked into the final product. Because wind power technology is just evolving in modern terms, it would be worthwhile to ponder the question as to where we should be heading in the development of this energy resource.

Long range planning is necessary because wind energy technology cannot exist by itself, it is part of a tremendously intricate system inhabited by people. As a result of this, plans should be made in the context of the various aspects that must be considered to develop it effectively.

While many technologies have come and gone, the people, the businesses and other groups that form the market place go on relatively unchanged through the centuries. For this reason, it would seem profitable to look into the past for successful technologies, to consider the reasons for their success and then to apply them in providing directions for today's wind energy programs. Such a study should be able to provide a sense of long term direction or directions. These directions must include the many factors that will be considered if wind energy is to become a really valuable power source. In fact, it is probable that our experience in the future will show the wind turbine itself to be a relatively small, but vital part of an effective wind energy technology.

THE ROLE OF THE AUTO INDUSTRY IN TRANSPORTATION TECHNOLOGY

Although there may well be many successful technologies, each with their own lessons that could be applied to the development of wind energy, from the wheel through the lever, there can be no more successful technology existing today than that of transportation. The primary reason for its success must certainly be the flexibility that the designers have used in developing applications tailored to it's multitude of highly specialized requirements. From skateboards to high speed trains, from the piper cub to the Concorde supersonic jet and from small outboards to supertankers, all of these effective transport modes have been developed as extensions of the basic requirement to move something or somebody from here to there. This concept of tremendous diversity must be carried over as one of the central themes in developing an effective wind energy technology. That is, a broad scope of specially designed pieces of equipment tailored to specific jobs.

We are making a mistake, I think, in concentrating on large wind turbines. The projects being done at this level are fine. Large wind turbines are a necessity, they will be a necessity for the future. However, there should be a wider scope, a greater flexibility in our approach to wind turbine design. To access that mass market, the wind industry needs the 'Model-T' small wind turbine, which can be installed anyplace and do an effective job. In fact, it is likely that no 'one' design will ever meet all our needs. This suggests then a development evolution into 'lines' of small wind turbines analogous to today's availability of different makes and models of cars.

In all probability, the segment of the transportation technology which has had the longest, most spectacular success and the greatest impact on society as a whole is the automobile and, more particularly, the family sedan. It is an omnipresent element throughout most of the world today. The mass market enjoyed by the automobile is based on four simple, but vital factors: it is effective, it is low cost, it is reliable and it requires essentially no maintenance.

The mass market needs a small wind turbine which meets these four requirements and is capable of being installed on individual homes, factories or any structure. Present turbines around 10 kW and greater cost anywhere from $1,000. - $3,000./kW which is simply out of the range of most of the pocketbooks of the general public. However, if you start talking about small wind turbines, about $1,000. or less, that can be installed anyplace, then you immediately have a basis for a tremendous mass market. Anybody could afford one of these. This is the central premise.

The mass market for automobiles did not come about without a huge amount of effort and careful, thoughtful engineering over the span of many years. In many respects, the wind turbines of today are similar in their state of development to the automobiles being hand-built in the first years of the 1900's: they are big, expensive and do not do much. While this may seem to be a harsh criticism of the wind industry and its designers, it must be realized that that highly effective device, the modern automobile is not only an evolutionary product resulting from many years of development, it is just one part of an extensive and intricate system. If, by some bit of legerdemain, one of our modern autos could be returned to those early days, it certainly would be even less utilitarian than a Locomobile or similar equippage simply because today's design is compatible with today's conditions, as the Locomobile was for its era. It would be difficult to imagine the auto owners of those early days, with their ladies in full skirts and feather-laden bonnets becoming overly enthusiastic about today's compact sedan. Even the male driver of that era, although less encumbered, would have found it hard to adapt to the contortions required for entry which are now a part of motoring. Those Ladies and Gentlemen were accustomed to climbing up into roomy carriages and would have had no particular interest in changing their ways. Therefore, it must be accepted that for wind energy technology to expand on a broad front, and to allow its coming of age quickly, it must be developed as an integral part of the society and the country in which it will be used.

SIMPLICITY AND FLEXIBILITY IN WIND TURBINE DESIGN

The primary requisite in developing a mass market for wind turbines is quite simply stated; we must create a variety of designs that can be used effectively in different locations and different ways. A concomitant of this basic consideration is that the designs be compatible with society. For it is obvious, at least in the United States today and the other countries which could develop mass markets, that the major potentials for such markets exist mainly in the cities and the crowded urban areas. Considering such potential markets, it is readily apparent that most of the existing designs are just not appropriate for siting in any but quite remote places. In fact, the Wind Industry, and the Nuclear Power Industry have both developed their respective arts in such a fashion that the wind turbine and the nuclear power plant are fit only for placement in technological leper colonies. Developing a product for any mass market requires that the product have the inherent capability of being integrated into the society for which it was intended and where the market exists. But wind technology, as any other, can readily be redirected once those who are working on it become convinced that there are other approaches which should and must be explored.

Going back to the analogy of the vastly different eras in automobile design, if the Locomobile were transported into the present, it could not be driven on any of out highways; it would not meet any of the legal, social or technological requirements for daily operation. While automobiles and the present legal/environmental requirements for regulating them grew and developed hand-in-hand, the wind turbine of today is faced with an existing body of laws developed without consideration of any but existing technologies. The two can and must be made compatible with each other. The wind power industry not only has the task of new hardware design but also the more difficult task of educating the public and revising the laws of the land.

THE FAMILY CAR AND THE SMALL WIND TURBINE

The family sedan, which has been selected as a model for the mass market wind turbine design, has quite a few built-in limitations: it will not carry much and it is pretty well confined to the limits of the established highway systems. But, for its set purpose to carry four in safety, reliability and at a reasonable cost, it is one of the best designs ever developed. Just as massive transportation of goods is accomplished by train, air, truck systems, so can the large scale power generation be supplied by megawatt wind turbines which then become an effective part of the regional power grid. Similarly, just as daily commuting for the individual is served by the family sedan, millions of small businesses, homes, farms, schools and other public buildings would benefit substantially from small scale wind turbines which provide supplemental sources of energy for the non-grid supplied loads. In carrying this basic concept of utility into wind turbine designs for the masses, it requires immediately that the wind turbines be easily mounted on individual homes, factories and other buildings or structures.

WIND SYSTEM COSTS

One hears about reductions in wind turbine unit costs as the production volume increases. However, the predictions of reduced costs for wind power as compared with the cost of fossil-derived power is a most unlikely development. It is unlikely to occur simply because all aspects of the cost of wind turbine systems are directly related to the cost of energy. Not only in the materials used in the wind turbine itself but in all the factors which contribute to the final wind system costs: housing, transportation, salaries, and all the other myriad elements.

In the past we have been able to ignore energy because it was so inexpensive. Our thinking to a large extent has not changed, even today. We unconsciously feel that energy does not cost us that much, although it now drastically affects every aspect of our life.

While there may be some possibility for reducing costs as wind system use increases, the present wind turbine designs really do not have the inherent capability for major reduction in cost due to quantity production. The one real possibility for significant reduction would be a design break-through. However, given the present narrow approach to wind turbine design, such an event is not likely to occur.

While it is true that the power of a wind turbine increases as the square of the rotor diameter, the costs of an installation probably increase at a faster rate than the power. Moreover, the legal, social and environmental problems do appear to escalate as the third or fourth power of the increase in rotor diameter. It is also true that the low capacity wind turbine costs less and thus more of the population are able to afford them. Finally, the smaller unit will begin to produce power at lower wind velocities than will its larger relative. Since low wind velocities and low incomes are distressinly common occurrances, the smaller wind turbines will not only attract a far larger group of buyers but they will utilize the low wind velocities and thus will present an excellent investment. The convenient rationale for ignoring these low wind velocity bands is that there is not much energy in them.

THE WIND INDUSTRY TURN-ABOUT

This is an extremely odd turn-about for the industry. The modern wind power technology was started by Marcellus Jacobs, Palmer Putnam and others who were willing to fly in the face of conventional wisdom: that the energy density of the wind was too low to make it worth bothering about. But today, the accepted conventional wisdom within the wind industry is that there is not enough energy in the low wind velocities, and the frequency of the high wind velocities is such that they are not worth considering in the design of wind turbines. While it may be true that the present state of the art in wind turbine design is such that these extremes of the wind velocity bands can not now be utilized effectively, to use the present limitations as justification for continuing them is most short-sighted. A major lesson that we must include in all work on the renewable energy resources is that there can be no energy source ignored.

HOW UTILITIES CAN BOTH HELP AND PROFIT

Given a really effective, reliable group of low cost wind turbines, the utilities should become increasingly and directly involved in wind power. The leasing of small, non-grid connected wind turbines, as supplemental power sources, to the utilities' customers would provide an attractive means for increasing generating capacity and one that does not incur the heavy financial and legal burdens which are usually connected with the start-up of large central power plants in today's congested country-side. The installation of small wind turbines would not involve heavy capital outlays, would not involve lengthy environmental impact studies and further, would not even involve the costs associated with the acquisition of land. By connecting such wind turbines to hot water heaters, to space heating systems and in the future, to the outlets for recharging electrical vehicle batteries, they would be able to replace a part of the fossil fuel derived power. While each of these installations would produce only a small amount of power by normal power station standards, in the aggregate they would provide a very effective tool in our effort to replace fossil fuel derived power with power from alternative energy sources. As an example: there are approximately two million people in the area of Philadelphia. If just one in every one hundred had a 1/2 kW wind turbine, the aggregate new capacity would be ten megawatts. It is difficult to envision the installation of four 2.5 megawatt wind turbines anywhere within 50 mile of Philadelphia. Watt for watt of new generating capacity, the smaller wind turbines should prove to be far more effective than the large units. Not only are they close to the loads for minimum line losses but they do not incur the operational inefficiencies which are true for the grid-connected wind turbines and they would utilize the more common lower wind velocities. If the utilities owned and leased these supplemental generating units, they would be realizing a steady income.

OTHER CONSIDERATIONS FOR WIND SYSTEM FLEXIBILITY

Although developing a body of effective, high reliability, low cost wind turbines is a necessary part of the overall goal to expand the capabilities of our wind energy technology, it is only one part of a multi-faceted system. There must be comparable expansions in the many user systems that will interface with the wind turbines in a broad, integrated body. These systems must be capable of using a variable voltage, variable frequency power directly from the wind turbine. The wind turbine must, to the greatest extent possible, be removed from voltage/frequency regulating constraints and thus be free to operate at maximum efficiency under all wind conditions. We need, in addition to wind turbine designs that are people-compatible, a great increase in the variety of wind turbine types and more flexibility in our applications. This flexibility must include wind turbines in stand-alone systems, and in hybrid systems in conjunction with solar and hydro. Finally, we must develop our thought processes to the place where wind power is not synonymous with wind turbines; a wind turbine is just one method available to us for utilizing wind energy. In essence, the present limitations stem primarily from lack of experience and lack of imagination.

MORE ON THE NEED FOR INTEGRATED PLANNING

While the above is critical of the wind industry, it represents criticisms not so much of what is being done at present but of what is not being done. One gets the feeling that there are no long range goals that have been set; no overall philosophy concerning what we should be doing to create a really effective body of wind energy systems. There are very few papers in the wind energy symposia and conferences that consider what the major goals should be for the industry; where we are at present and how best to achieve these goals. The industry seems content to design and build wind turbines in a very restricted range of design types, mostly for grid-connected applications and for installation in wind farms. This approach appears to have a serious limitation; rather like casting one's bread upon the waters and letting it go at that. All too frequently this yields nothing more than soggy bread. However, there is definitely a plus side to the wind turbine situation and that is that there are more being installed every day. Each unit that goes on line can not but help add to our knowledge of the technology. Good, bad or indifferent, each installed machine will provide the additional experience that is necessary to begin developing a solid foundation on which to build.

INTEGRITY, INTEGRITY

One of the requirements for a sound wind energy technology that was mentioned early in this paper is integrity. In some cases, the wind turbine manufacturer's whole way of life is devoted to developing effective and reliable designs. When problems occur, as is bound to happen with any relatively new and untested machines, these manufacturers leave nothing to be desired in the way of support provided in such times of trial. There is, however, one area where most manufacturers, both the highly motivated, and the others, leave much to be desired with respect to integrity. That one area is the supression of their installed wind turbines' actual power production for a year's operation. The advertising bulletins supplied by the manufacturers have detailed power curves and predicted power production for a range of average, annual wind velocities. One manufacturer states that his data are so good that he can look at the zip code on a letter and tell immediately what a wind turbine in that area would produce in the course of a year. But, despite having a total of many thousand wind turbines installed by now and operating on a regular basis, neither this manufacturer nor most of the others, will make available or publish the actual power production records of their installed wind turbines. The reason for this industry-wide policy is simply stated: the actual accummulated time for power operations during the course of a year and the power production are disappointing. But they are only found to be disappointing when viewed in the context of the wind turbine's capabilities as implied by the manufacturer's advertising. In perpetuating this, the industry is doing itself a great disservice. It promises more than the wind turbines can deliver. While there are cracks just beginning to develop in this wall of silence, they are still, regrettably, the exception rather than the rule.

A LESSON FROM THE NUCLEAR POWER INDUSTRY

In this lack of full disclosure on the part of the wind industry, there is a very disturbing parallel with the path followed by the nuclear power industry. Each has promised more than the technology can deliver. While the reasons are different for each, the end result can only be the same; a loss of credibility for the industry in the minds of the public. The simple, basic fact is that each installed wind turbine is to some extent reducing our use of fossil fuels. That is what the wind industry has to offer and that is what it should be selling, not economics.

The difference in reasons for this lack of frankness and complete disclosure by the nuclear and wind power industries are most interesting and the results, it appears, are 180 degrees apart. The curious part is that both stem from an unfounded belief in their own industry press agentry.

The commercial nuclear power proponents started out with the slogan that nuclear power is safe, clean and low cost. The nuclear groups more than anyone else, fell for this nonsense and as a result payed little practical attention to keeping plant costs down.

I have been working in the nuclear power business over these many years. I feel that for all practical purposes, nuclear power has been killed. The curious thing is that it has been killed by the very people who are in it, who would have had the most to benefit out of it if it had continued healthy. The architect-engineers developed systems that are just too expensive, they simply do not do enough. Some utilities have tried to operate these plants in the same way that they operate their fossil fuel plants. I feel that the nuclear plant is extremely safe as far as the populace is concerned, but they will self destruct very easily, as happened at Three Mile Island.

When the reality of the true costs of nuclear power became all too evident to those designing the plants, particularly for the more recent and large scale plants, complete disclosure would have brought the projects to a halt. In the recent past, these huge costs have begun to surface and as a result, nuclear power in the United States is essentially dead -- killed not by the Intervenors or by the Environmentalists or by the safety aspects, but by the economics when considered in the light of that industry's well earned lack of credibility.

It was not too long ago that the nuclear press was predicting that the power from nuclear power plants would be so cheap that no one would bother to turn off the lights. Nuclear power in the United States in the not-too-distant future will be looked upon as either a black joke or a disaster, depending on the energy picture at the time -- a technology that was killed off before it had time to mature. And all this at the hands of those who had the most to gain from its continued growth.

HOW THE WIND INDUSTRY CAN BENEFIT FROM THE NUCLEAR LESSON

The wind power industry has been similarly bemused by its own press agentry; namely, that wind power is already an economically viable power source. In general this is not the case. Even for wind farms with their government incentives, which only serve to distort the true picture of wind power, the satisfactory balance sheets for such ventures can be accepted only as an article of faith at this time. There is no basis in operating or fiscal experience on which to depend for an estimate as to the rationality of such programs. In an effort to live up to its press agentry, and in interesting contrast to the nuclear power industry, the wind power industry approach appears to have been to keep its prices for wind turbines at unrealistically low levels. As a result, manufacturers are faced with the need to sell their products wherever and whenever possible, no matter how ill-advised the project might be. It is simply a matter of survival. And it must be accepted that the survival and good health of the wind power industry, and of the other renewable energy technologies is a necessity.

The answer to this situation, at least for the wind power industry could be quite simple: just tell the truth. The truth is that modern wind power technology is in a pioneering phase, it is expensive and it has not yet been developed to the desired state of reliability. But it can never correct these deficiencies until there is sufficient operating experience to provide the desired reliablility and sufficient volume of manufacturing to reduce costs.

In many cases today, except for special situations such as high wind velocity locations or tax incentives (especially for windfarms), wind power is not an economically viable source. If wind energy stays pretty much at its present relative cost to other energy sources as the years go on, then one should not try to sell it solely on the grounds of economic viability.

The thing is, it is a necessity.

We HAVE to use it in order to reduce our use of fossil fuels. We HAVE to use it for a smooth social transition from a fossil fuel economy to an alternative energy economy. The only way to realize this is to start now and say: "WIND ENERGY IS A NECESSITY". Let us sell it on that basis. When wind energy is sold on the basis that it is a necessity to help us into the future, then the question of economics goes 'out the window' to a large extent.

Those who are buying wind turbines today, not considering wind farms, are doing so because they can afford them, because they believe that by using them they will be helping to reduce our use of fossil fuels and because they realize it is a necessity and want to help the industry to progress, develop and grow.

While not in it for the dollar returns, these buyers will gladly accept the assumed return on investment suggested by the manufacturer as a good excuse for doing something they want to do anyhow. On the other hand, given this initial bias, potential customers will accept just as readily the concept that they are helping in the pioneering of a new technology by buying the wind turbine: that they are helping to bring wind energy up to its true potential and thus in turn helping to provide an orderly transition from a fossil fuel to an alternative energy economy. Again, the concept should be stressed that what the industry has available to sell the public and what it must be selling, is the gradual reduction in the use of fossil fuels as the use of wind energy increases.

The history of using advertising as a substitute for engineering to bolster sales is replete with dissatisfied customers and assorted disasters. Instead, the industry should be educating the public because it is the public who buys wind power.

Although manufacturers might disagree, the alternative approach suggested above should not reduce sales, even with a more equitable pricing structure for the wind systems. On the other hand, it will most definitely eliminate the disillusioned customer.

EDUCATION

It is particularly a pleasure to be at a symposium that somebody else organized. I've been through two of them and I realize the problems involved. While the number of people attending this one is considerably less than the two that I organized, I do not feel that there is any correlation at all between quantity and quality. I have felt for some time that more smaller symposia, such as this one, are far preferable to the tremendous affairs that go on for 3 or 4 days and attract maybe 400 to 500 people. I do appreciate being here.

SOUND IMAGINATIVE ENGINEERING

I have come upon some good examples of this thoughtful approach here today such as Mr. Brown's work on the Orkney Island wind turbine. I was most impressed by the monorail hoist placed in the nacelle so the machine could be serviced without bringing in a cherry picker or special crane. Also the drawbridge in the column to service the tip flap. That is very sound engineering.

Another came when listening to Malcolm Lodge field a question on energy storage for wind power at the press conference. After mentioning a couple of alternatives, he also said that 'the process itself could be used to store energy'. He illustrated this with the waste disposal plant on P.E.I. where the pumps had been run on a straight line basis of continuous output all day long. But he found when he investigated this that the pumps could be shut off for up to sixteen hours per day, which was in effect an energy storage situation in the process. With this discovery, he realized that a wind turbine could be very effective because it would not have to supply power every minute of the day. This did not cost anything in terms of new equipment or research programs, just a good example of imaginative engineering, the type required to establish a long term industry.

PLANNING FOR THE FUTURE

It is now time for the wind industry, in concert with the utilities and interested government and consumer agencies to gather 'round and develop a comprehensive body of realistic and useful long range wind energy plans: a group of plans which will benefit all concerned. This will insure not only the survival of the wind industry but will promote its continued growth and effectiveness. The keys to the successful completion of such plans are: integrity, education and sound imaginative engineering, in that order.

WECS UTILITY INTERCONNECTION STANDARDS

Roy Patterson, P.Eng.,
Standards Administrator
Canadian Standards Association

The figure is the CSA monogram. I think you are all familiar with the CSA mark. It is used on something like half a billion products annually. Our standards cover everything from abbreviations to x-ray equipment.

The high visibility of the CSA mark is also recognized by the government and we cooperate with them on many programs. This not-for-profit association contracts its services with the government where a national need is identified and industry is not in a position to provide the funds necessary for the programs. In the case of the Wind Energy Program we are indebted to the NRC and also to the Department of Supply and Services for the funds that we need to operate the program.

Before proceeding, I would like to put in a plug for one other government program that I am involved in. It is a program that is covered by the Department of Consumer and Corporate Affairs. That program is the EnerGuide program.

The EnerGuide program began quite a few years ago and it has been very successful. We are all interested in conserving the supply of fossil fuels. To help achieve this, the program measures the energy consumption of all six major electric appliances. It lists this monthly consumption on the EnerGuide label (figure 2), that appears on every product. This information is also printed in the EnerGuide Directory by all the brand names and model numbers of the major appliances. Copies are available from either the CSA or Consumer and Corporate Affairs, Canada.

To give you some measure of the results of this program, without trying to identify them as entirely EnerGuide, I refer to figure 3, the 15 cu. ft. frost free refrigerator, which is a common refrigerator in the market.

Looking at the fleet average of a 15 cu. ft. frost free refrigerator in 1979, it's energy consumption was around 153 kW-h/month. In 1983, by design modifications, it is now down to 123 kW-h/month. That savings, for just one unit, does not look too interesting. But, when you multiply by the number of units sold in Canada from 1979 to 1983, the savings is about 16 million dollars in electric energy at 4 cents per kW-h. This is equivalent to avoided costs for something like 50 MW of generating capacity at a 100% load factor because of the modifications to just the refrigerator alone.

With respect to the Wind Energy Program, figure 4 shows the CSA organization structure. The technical committee of the wind energy conversion systems aspect reports to the standards steering committee on solar and wind energy that was referred to earlier by Marc Chappell. This work is financially supported by the National Research Council and the Department of Supply and Services.

The wind energy technical committee developed nine objectives which are shown in figure 5. I am not going to go into them in detail, you can scan them as rapidly as I can mention them.

We have established three sub-committees to date. The first sub-committee was the one on safety standards for small wind energy conversion systems. Figure 6 is the scope established for this sub-committee. At the last symposium we talked about the scope. We are now up to the point where we are actually going to submit the first draft of this standard to the technical committee tomorrow at a meeting.

Figure 7 is the scope established for the performance sub-committee. As you can see, we are looking at performance features.

We now come to the main subject of our discussion today and that is the utility interconnection standard. This technical committee was formed just about June of this year, with three meetings held to date. Figure 8 illustrates the scope of this committee set at the July meeting. In detail it applies to:

- installation
- utility requirements for interconnection
- metering line outage protection
- manual and automatic disconnect
- transformers, etc
- isolation, start-up, restart control characteristics and procedures
- it does not apply to the methods used to generate power which are covered by some of the other standards.

We are talking about utility interconnection in this scope, for this standard. It is the definition of a 'Parallel Interactive Generating System'. PIGS for short. I think it is well worthwhile to dwell on it for a moment, to understand what we are concerned about.

It is:

"a consumer's electric power production system which is operating in parallel with, and capable of delivering energy to, an electrical supply authority system".

That is the system we are interested in with utility interconnection.

Having established the first part of the standard, we are now looking at what goes into the standard. In the initial stages of standard development, we are following the formats of AWEA and ASTM who recommend grouping criteria under:

a) installation requirements
b) operation requirements
c) performance requirements

INSTALLATION REQUIREMENTS

The first important point which needs to be repeated is that we are preparing a standard for parallel generation. It is a cooperative effort between the owner/user and the utility to communicate and as early as possible in the planning stage.

We have established as the first requirement what the owner/user of a WECS proposing an interconnection shall make available to the interconnecting utility the information listed in figure 9 prior to actual interconnection.

The owner/user should expect the utility or utility representatives to review the submission and the potential owner/user shall request the utility to review the installation and operating specifications for acceptance for interconnection prior to interconnection. This review should insure the potential WECS owner of acceptance before incurring financial responsibility for the WECS. This is not to be construed as an approval by the utility on the performance, reliability, or quality of the WECS proposed.

There should also be a final approval, and we are proposing:

"Prior to the initial operation of the interconnected WECS, the equipment installation shall be approved by the utility."

The WECS owner/user also has a responsibility to update the information to the utility and we are proposing:

"The WECS owner/user shall notify the interconnecting utility of any modification to the WECS interconnection prior to implementation of such modifications."

It is also necessary that the utility feedback to the consumer comments on those features, and the utility is expected to give a written reply to the the written requests from the consumer.

OPERATION REQUIREMENTS

Line Outages

The committee is also interested in line outage (figure 10). We will be discussing criteria at our next meeting so that the interconnected WECS shall not in any way energize an electrical system that has tripped out. It shall be de-energized too, of course. It shall have start-up controls which provide safe operation for personnel and equipment under normal operating conditions upon resumption of service after a utility or WECS outage.

The line safety switch is very important and we are proposing:

"Each interconnected WECS installation shall include a manually operated disconnect switch. The switch shall be lockable in the open position and shall be located in the vicinity of the electric utility metering equipment or as agreed upon between the owner/user and the utility. Operation of the switch shall permit isolation of the WECS from the utility service. The disconnect switch shall have sufficient load interruption capacity to interrupt the maximum output of the WECS."

This brings us up to date on where we stand with the interconnection sub-committee. The work that will continue is listed here in brief. We are looking at:

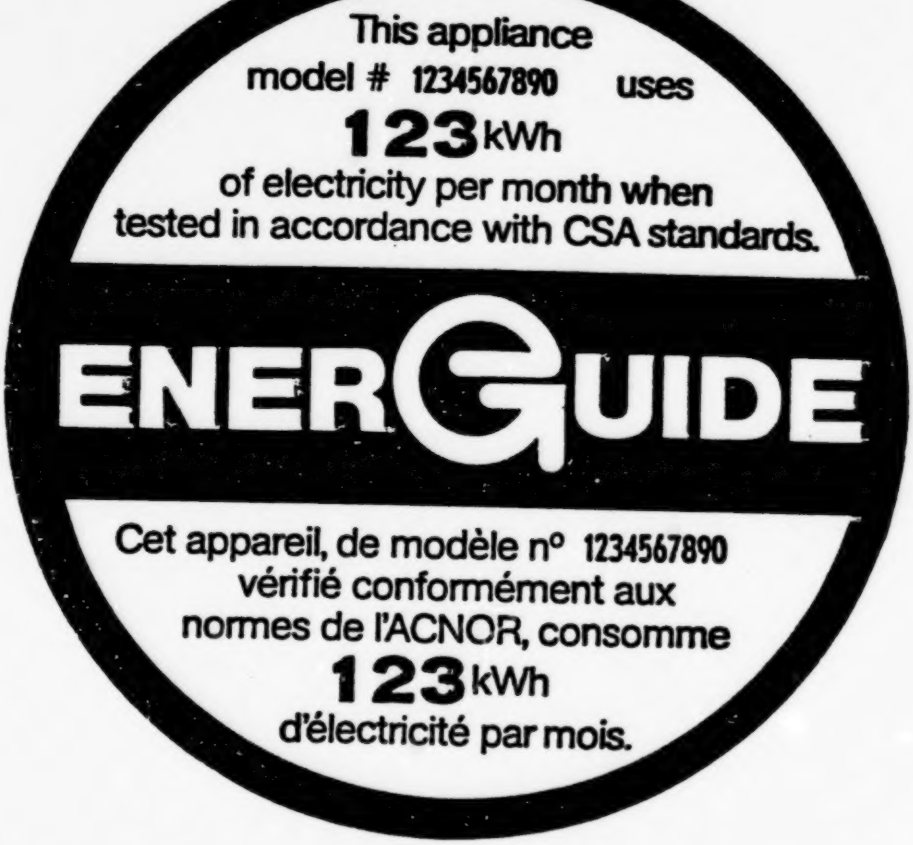
- metering
- manual disconnect switches
- isolation transformers
- installation maintenance
- utility system transients
- system start-up - safety and stability
- system de-energization
- certification
- current and voltage specifications
- power factor specifications.

This standard is expected to be in place some time in early 1985. The safety standard we hope will be out for public review sometime early in 1984, with the performance standard sometime towards the middle of 1984. Thank you.

Fred Schwartz:

Thanks Roy. As I stated before he came on, I think the work that CSA is doing is really critical to the establishment of a viable, strong industry in Canada, and to consumer confidence. I for one am very pleased that the work is occuring and thank Roy for being here today.

Figure 2



This appliance
model # 1234567890 uses
123 kWh
of electricity per month when
tested in accordance with CSA standards.

ENERGUIDE

Cet appareil, de modèle nº 1234567890
vérifié conformément aux
normes de l'ACNOR, consomme
123 kWh
d'électricité par mois.

Transparency Frame Reorder No. 3R324 Visual No. _____ Subject _____

Figure 3

AVERAGE - 15 CU FT FROST FREE REFRIGERATOR

1979 - Energy Consumption 153 Kwh/Month

1983 - " " 123 Kwh/Month

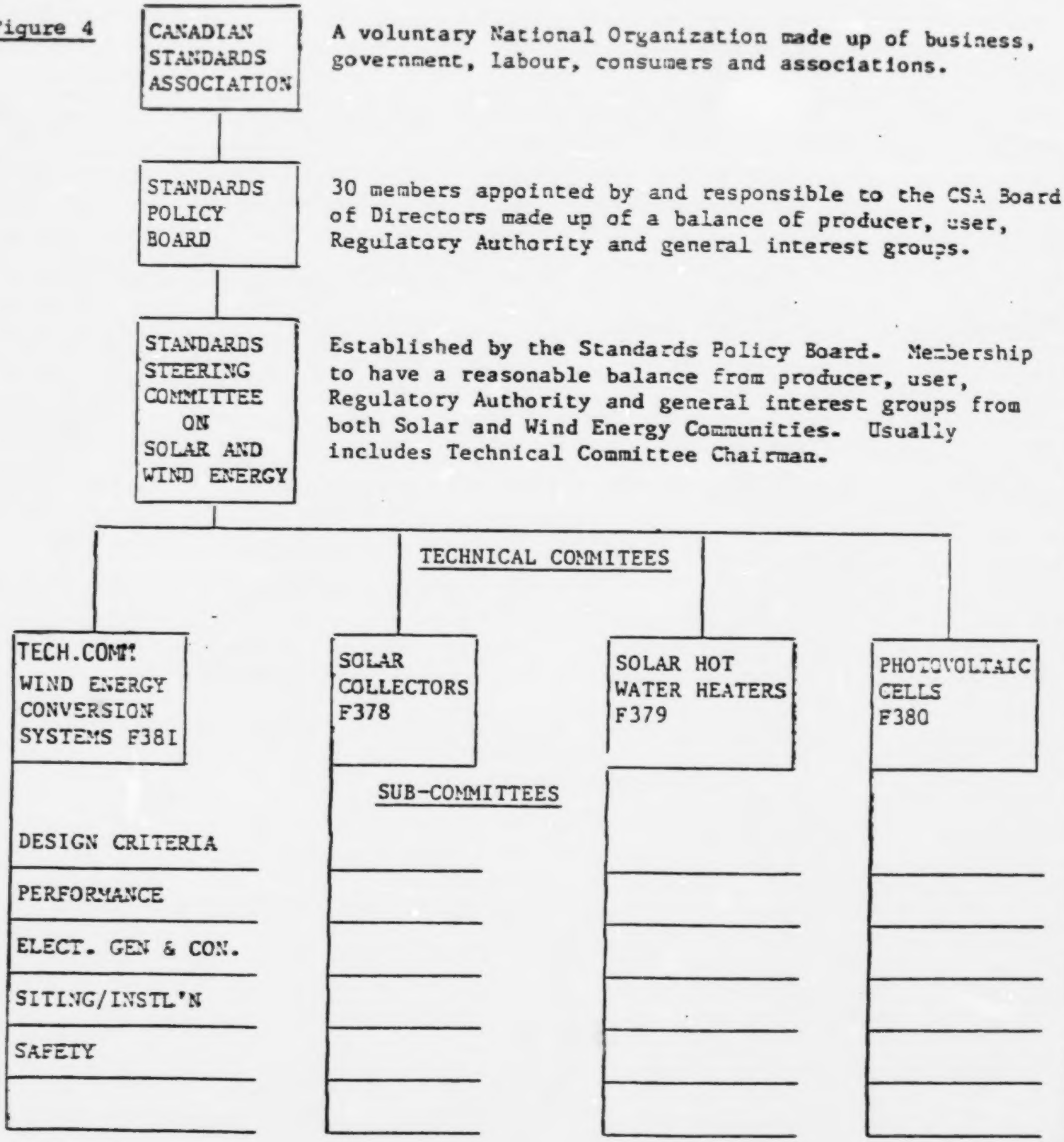
SAVINGS - 1983 - 16 million dollars
(Assumption - Energy Cost 4c/Kwh)

OR 50 Megawatts of Capacity

OR Equipment Cost

CANADIAN STANDARDS ASSOCIATION: As related to Solar & Wind Energy Standards

Figure 4


CANADIAN STANDARDS ASSOCIATION
STANDARDS POLICY BOARD
STANDARDS STEERING COMMITTEE ON SOLAR AND WIND ENERGY
TECHNICAL COMMITEES
TECH.COMM WIND ENERGY CONVERSION SYSTEMS F381
SOLAR COLLECTORS F378
SOLAR HOT WATER HEATERS F379
PHOTOVOLTAIC CELLS F380
SUB-COMMITTEES
DESIGN CRITERIA
PERFORMANCE
ELECT. GEN & CON.
SITING/INSTL'N
SAFETY

A voluntary National Organization made up of business, government, labour, consumers and associations.

30 members appointed by and responsible to the CSA Board of Directors made up of a balance of producer, user, Regulatory Authority and general interest groups.

Established by the Standards Policy Board. Membership to have a reasonable balance from producer, user, Regulatory Authority and general interest groups from both Solar and Wind Energy Communities. Usually includes Technical Committee Chairman.

TECHNICAL COMMITTEES - Responsible for the technical content of standards. Established by Steering Committee, the membership should have a similar balance. Usually includes subcommittee chairmen.

SUB-COMMITTEES - Responsible for providing technical knowledge, ideas and experience towards development of standards. Should reflect a national consensus of producers, users, regulatory authorities and other interests.

Figure 5

2...

The objectives of the Technical Committee on WECS are to:

1. Provide means of measuring performance. (Wind speed vs power output) so that one machine may be compared with another.
2. Provide a means of measuring the amount of wind available at a location so as to insure that sufficient energy will be available for the intended purpose.
3. Provide a method of installation which will be safe.
4. Provide manufacturers with a guide as to the various aspects of aerogenerator design they should concern themselves with throughout its development.
5. Insure that the structure is inherently safe.
6. Provide guidelines of how the electrical connections shall be made to an aerogenerator. In this area interconnection to the grid is of major concern.
7. Insure that the certification agency can adequately perform all the required tests.
8. Provide label information that will be useful to the user and certification authority.
9. Provide a glossary of terms, so as to minimize misunderstanding of the standard's intent.

Figure 6

SAFETY STANDARD - SMALL WIND ENERGY CONVERSION SYSTEMS

1. Scope

1.1 This Standard is concerned with the safety of Wind Energy Conversion systems including design and operation under environmental conditions.

1.2 This Standard is concerned with systems of 100 kW or less of rated power, mechanical, electrical or thermal.

1.3 This Standard is concerned with all sub-systems of SWECS including Protection Mechanisms, Supporting Structure and Foundations.

1.4 This Standard is concerned with the components and materials supplied by the manufacturers, with the adequacy of the assembly installation, maintenance and operation instructions, and with the safety of the system after assembly according to those instructions.

1.5 This Standard is not concerned with the siting of SWECS, interconnection to the power grid, SWECS performance, or effects of SWECS on the environment.

1.6 Compliance with this Standard does not relieve any person from the responsibility of observing applicable local, provincial and federal regulations.

1.7 This Standard covers minimum requirements and is not intended for use as a complete design specification or instruction manual.

1.8 Where reference is made to other publications such references shall be considered to refer to the latest edition approved by the organization issuing the publication unless specifically noted otherwise.

Figure 7

WIND ENERGY CONVERSION SYSTEMS

1. Scope

1.1 This Standard specifies methods for determing and reporting performance charactierstics of Wind Energy Conversion Systems.

1.2 This Standard applies to WECS having mechanical, electrical or thermal output.

1.3 This Standard is not concerned with noise except to report the overall noise level.

1.4 This Standard does not address issues of reliability, safety or durability except with specific reference to performance.

1.5 This Standard is not concerned with the siting or installation of WECS.

1.6 This Standard is not concerned with electro-megnetic interference.

Figure 8

UTILITY/INTERCONNECTION (WECS)

1. Scope

1.1 This Standard applies to utility interconnection.

1.2 This Standard applies to the installation and operation specification that will be made available to the interconnecting utility by those proposing interconnection.

1.3 This Standard applies to the utility requirements for interconnection (WECS)

1.4 This Standard applies to the metering, line outage protection, manual and automatic disconnect switches, transformers, fault-protection (and other equipment) for the safe interconnection to the utility system.

1.5 This Standard applies to isolation, start-up and restart control characteristics and procedures, and the quality of power such as limitations of output, harmonics, lamp flicker and power factor.

1.6 This Standard applies to installation and use of WECS in accordance with the rules of the Canadian Electrical Code, Part I for other than hazardous locations.

1.7 This Standard does not apply to methods used to generate power, transmit power, control of electrical sub-systems, or the conditioning and storage of energy.

Figure 9

A. REQUEST TO UTILITY FOR REVIEW OF WECS

Each owner/user of a WECS proposing interconnection shall make available to the interconnecting utility the following information prior to actual interconnection:

One line diagram of the WECS electrical system

A written description of the normal and failure mode operation of the WECS electrical system.

A table of WECS electrical characteristics including but not limited to type of generator (induction, syncronous, or inverted).

Rated and maximum output, kw and kva.

Rated generator voltage, generator voltage tolerance.

Rated generator current.

Power factor at 25, 50, 75, and 100% of rated power.

Rated generator frequency and tolerance.

Voltage/current harmonic characteristics at 25, 50, 75, and 100% of rated power output.

Performance curves (expected power point).

Maximum inrush current drawn during starting or normal operation.

Site specific information and drawings.

Figure 10

Line Outages

1. The interconnected WECS shall not in any way energize the electric utility service after a utility outage has occurred.
2. The WECS system shall de-energize or disconnect from the utility system within 0.5 seconds and not damage other connected loads or compromise safety of the utility system.
3. The WECS electrical system shall have start-up controls which provide safe operation for personnel and equipment under normal operating conditions and upon resumption of service after a utility or WECS outage.

"LIABILITY AND RISK IN THE WIND ENERGY INDUSTRY: AN INSURANCE PERSPECTIVE"

Arthur Despard,
Senior Vice President
Reed-Stenhouse Limited

I know at this time of day the last thing you want to hear is insurance jargon which is boring at the best. I was very interested in listening to your previous speakers. I go to a number of these gatherings and frankly I find it a tremendous privilege to hear such a large number of intelligent people. Listening to Frank Kaminsky I did not understand a word he said other than the kite problems and I have never been able to fly a kite either.

The comments of Neil Finlayson were probably as intelligent as I have heard anywhere. They certainly struck home with our industry, as well as with yours. A lot of common sense there and I think you should listen. The one thing that did please me was the little reference to disillusioned customers, I thought that was probably unique to the insurance business. It seems that it is not.

This is your sixth symposium. I have seen the beer ad on TV with the little thing on the cottage and that's to date my full association with the wind energy field.

I am surprised that you are six years old. It is a new industry. I think you are lucky because it is a new and vibrant industry and must be very exciting for you.

Probably the fortunate thing is that the innovation you have had to date to develop an industry of this sort does not have to be duplicated to any large extent in the insurance business to give you some coverage.

What you need is what pretty much everybody else needs in the insurance business. You need a liability policy, probably some general direct damage cover such as: wind storms, hail, theft and fire cover, construction cover of course, design engineering liability cover and so forth and so on.

I won't remark much very more then on the standard cover that an industry or people such as you need. I assume we have manufacturers, installers, designers, and so forth in the crowd. The best advice I can give to you is to find yourself a good insurance broker and talk to him. I think a good solid insurance program is a necessity for particularly a growing industry.

What we are talking about is liability and risk in the wind energy industry. I will try to concentrate therefore on the liability exposure and the insurance that would normally accompany that liability exposure.

I am including the design process with the manufacturing process in anything I say. Ignoring the usual premises exposure, that is, slips and falls which everybody has, the main exposure in manufacturing is a products liability exposure. What I mean by product liability exposure is the production of an item that when sold causes injury to someone else. Your risk stems from a legal action against you resulting from the breakdown of the machinery itself. From an insurance standpoint it is important to realize that a policy covers bodily injury and property damage resulting from a product which you have manufactured. Note that the product itself must have malfunctioned in some way and caused injury to a third party which injury is insured by the policy, assuming negligence, and assuming you are liable for it. The mere fact that a product has malfunctioned and has stopped doing what it was intended to do, in your case generate electricity, is not a claim under a general liability policy, although it is a legal responsiblity for you as a manufacturer.

As mentioned before the design process is generally considered part of the manufacturing process. Many liability policies contain design exclusions. I must go into the fact that a liability policy is not like a automobile policy which is a statuatory form. A liability policy is specifically designed usually by a company for their own customers, or alternatively, by a broker for your particular needs. They differ from one another, therefore. I think a little bit of care in selection of the policy itself is important.

As I said, there is a design exclusion in several printed forms which read something along the lines: "excluding liability arising out of the rendering of professional services or the ommission thereof" which could be very difficult in the event of a suit brought against the manufacturer. The professional services are not usually defined any further than that. So it is a dangerous exclusion particularly following a claim where one of your towers has fallen on somebody, for example. Had it fallen because it was poorly installed, poorly manufactured or poorly designed? An insurance company will say, probably poorly designed. The question as to whether the injury arose due to a manufacturing defect or a design defect could at best delay and at worst remove cover entirely. So don't accept a policy with a design exclusion in it.

There are many independent consultants involved in the wind energy business who would specify the type of machinery to be used and the location where it should be placed for optimum utilization. If you are solely a designer, you don't need a liability policy of that sort. You need an 'engineering liability policy'. Frank Kaminsky, I would gather in his earlier talk, is purely a design or engineering consultant type firm. No manufacturing involved. The exposure is quite different from normal product exposure. There is likely to be no physical injury due to the negligence of a consultant. Rather there would be a financial loss to a user because the machinery is improperly placed, improperly specified, not practical for the use intended, or probably the wrong wind shear coefficient is given (whatever that was). For this situation a policy known as a 'professional indemnity policy' or an 'errors and ommissions policy' is required by the engineer to cover financial loss caused by his negligence.

Forgetting that, we turn to the general liability policy. It is important to note again that the product liability insurance is designed to protect the company with respect to physical damage to others, and bodily injuries caused by a defective product. Loss of use of property is covered, assuming that there has been some damage to the property for which the claim is made.

Now, suppose your machine fell on somebody else's power lines and broke them and cut off the power to a factory of some sort, although there has been no damage to the building, only damage to the power line. The loss of use of that factory, that is the time it is closed down as caused by the breaking of the main supply of power, would be covered by your liability policy.

Suppose instead that your machine simply blew over, did not damage anything but itself and cut off power to a factory. The normal liability policy, at least in the past, would not cover loss of use of the machine just because it blew over. Coverage was only provided for loss of use of other property that was damaged by the machine.

There have been some changes to the liability policy and again it is something that you have look at. If there should be sudden and unexpected physical damage to the machinery itself (it has to break apart), under some policies nowadays you will have the loss of use of that machine. So that the power that is not going to the manufacturing building would be covered - the cost of that back against you. If the machine simply doesn't do what it is supposed to do; if the machine doesn't put out the electric energy that you said it was going to; if it simply breaks down but doesn't fall down or blow up or something spectacular like that, then it is very unlikely that you would have any of that covered under a general liability policy, at least today. The big problem lies in the fact that there must be physical damage to the machine. The mere failure of the machine to perform is not insured under a general liability policy.

While commenting on the general liability situation, a short discussion on law and its application is necessary. We are located in Canada, so presumably manufacturing is done in Canada and most products are sold for use in Canada. As you are aware however, there is a considerable difference in law between Canada and in particular the United States of America. Canadian law is based on British common law, other than Quebec of course, and as the common law applies to product liability, negligence is required in order to prove legal responsibility against a manufacturer. In other words, it must be shown by the injured party that the product was manufactured negligently and was dangerous in order for that injured party to succeed in a legal action against a manufacturer. The situation in the U.S. is totally different in that a doctrine of strict liability has been adopted which in effect changes the onus of proof from the injured party to the manufacturer. All that the injured party must do is show that the product was defective and usually this can be done by merely showing that someone was injured by it. Under these circumstances it is the requirement of the manufacturer to prove that the product was not defective which of course is a much more difficult thing to do than merely defending yourself to show there is no negligence in its original manufacture. Actions brought under strict liability are far more costly to defend and generally end up more often in favour of the plaintiff than do actions brought under negligence.

When I was thinking about what I was going to say in 20 minutes, I thought probably the best thing I could talk about is the new product that is out which is the 'products warranty' cover. What that tries to do is take the general liability policy as it presently exists and fill in that gap of the failure of the product to do what it was intended to do. A recent innovation in the insurance business has produced a new liability form known as 'products guarantee - legal liability' insurance. What it does is back up your warranty.

The coverage is very narrowly underwritten. Very few companies provide the product at this time. It is experimental. Until a track record has been established by the pioneers of this cover, very few underwriters will be writing it. It started out in Europe, Lloyd's of London. A lot of things started out there. They've written it for some five or so years with no real luck. They have been relatively unsuccessful in it. Their claims experience is higher than anticipated and they have not sold as much of it as they would like to have done. But, they did not sell it in Canada or the U.S.A., they restricted it to Europe.

The first company to introduce it here was the American Home Insurance Company. They have been followed to my knowledged by two other companies but they are not rushing into it head long.

What a 'products guarantee' liability policy does is fill the gap between that which was formerly an uninsurable business risk and traditional product liability cover. The 'products guarantee' policy agrees to indemnify the insured for the insured's legal liability to repair or replace a defective product. So what it is really doing is backing-up your warranty.

You've produced this thing. The thing breaks up, the rotors break, the generator burns out, that kind of thing, you have guaranteed it. What this policy will do is back up your guarantee and pay the injured party on your behalf. I think the advantage of it to a new industry such as yours is it brings it

an awful lot of credibility from someone like myself who says. "I don't know if I want to spend $20,000. $200,000 - whatever they cost for one of these things. Well. will it work?"
So, you say it will. You give him a five-year guarantee. Have you got anything to back that up? Having an insurance policy helps.

Explaining this a bit further:

1) It indemnifies the insured for the insured's legal liability and that legal liability can manifest itself either in contractual liability. which is your warranty. or in common law.

2) "Repair or replace defective product". Repair is later defined in the policy as: "removal. treatment. alteration. fixing. transportation and the like". Replacement on the other hand is defined in the policy as: "the original selling price of the given product less the profit of the insured". You don't get to sell it and make money on it twice. You have to replace it. but at no profit. The policy will pay the difference.

Simply stated. the policy will either repair it or replace it. The maximum that would be paid is the replacement cost of the machine. This is the original selling price less profit.

Some features of the policy itself:

Generally. $1,000,000 is the basic policy limit. You can buy that easily. About $5,000,000 with a little time. That. by the way. is an annual aggregate limit as well which means you can only use it once in any policy year. That's a little restrictive. I think. If you have a product line for example that you have out in the field and they all start breaking down then $1,000,000 is all you have.

The policy form is a combination of a 'claims made' and a 'loss occuring' wording. I will not try to explain that to you because that's probably as Greek to you as all this other stuff was to me. What the policy is saying is that in order for a claim to be made under the policy there must be an occurrence. that is. something must happen. It must take place during the policy period and somebody has to sue you for it also during the policy period. Now. that is very restrictive for a brand new industry. In addition. only annual policies are issued. no three year. five year or extended policies which could be a bit of a burden when you are discussing long term warranties.

In order to get away. partially. from a loss that occurs on the last day of a policy year. they have said that there is a six month discovery period. If something happens on the 364th day of the year. then you have six months for someone to find out about that and take action against you. So it's really a year and a half.

The other point is that prior products are not excluded, the policy covers everything that has happened to date. If you have manufactured things for 100 years before, it covers all of those things you manufactured as long as they break down during the policy period and somebody sues you during the policy period. A product you manufactured 20 years ago and maybe found liable for today will be covered under this policy. As a result, since the policy is written on a 'claims made' form, if the underwriter limits guarantees to five years at a time, the underwriter is limiting his exposure to five product years in any one 'claims made' period. If on the other hand the insured was issuing 20 year guarantees, the underwriter would be exposed for 20 product years in one 'claims made' period. You see what I mean. It gives you a lot of back cover, which is not a lot of joy to someone in your business which is quite new.

Small Print, every insurance policy has small print. I think they are reasonably simple in this form.

The first exclusion, is simply a bodily injury and property damage exclusion. The reason for that is it is covered under a general liability policy or a traditional products liability policy.

Contractual liability is excluded. By contractual liability they mean additional liability that you, the insured, have assumed by contract from a third party as opposed to your warranty or guarantee. Note that guarantees, although they are contracts, are not excluded by the policy. Guarantees are contracts which clearly define your own liability. In other words, the policy excludes liability assumed by contract, not guarantees. Guarantees are part of the policy and are covered.

Your consequential loss, that is, loss of use or loss of profits caused by the breakdown, is an important thing that was excluded. There is a substantial amount of loss of use cover in a standard general liability policy. In some areas where the standard general liability policy would not apply, neither would this policy. In a case where there is an absolutely passive malfunction of the product, where it does no damage to anything else, but does create a loss of use or loss of profits problem, there is no cover. As a newer innovation, the insurers have produced an endorsement to remove this exclusion subject to a sublimit in the policy. By this, the cover for loss of use is much lower than the cover for the replacement of the defective product itself. The companies now have decided that they will provide some consequential loss cover. It is usually a percentage of the limit, in addition to the limit, and of course at additional cost.

Two other exclusions:

Products recall expense, that is, the cost of removing an entire line of bad products off the market. You can buy that if you want it at additional cost.

Design 'errors and omissions' cover. Again that is specialized and can be bought at additional price.

Generally they will only accept a 5-year warranty, nothing longer than 5-year warranties. At the present time they want to test their feet a little bit before providing anything longer than that.

I guess the most important question, the one that everyone will ask, is, "How much does it cost?". It is expensive insurance, there are deductibles normally incorporated. The underwriting is done mainly on an engineering basis and with a view to the degree of warranty given to the customer. Since it is new and is underwritten very specially, I can't really tell you, as it would require a submission to the underwriter to establish cost. I am told by the underwriter that the cost could range from about 10 cents to 5 dollars per 100 dollars of sales. A fair variety. Average on everything that is written to date is 65 cents per hundred dollars of sales.

Deductibles vary from 5 to 15% of the loss amount.

The minimum premium is $5,000 dollars a year.

I have been rather sketchy on an involved subject, but I have been too long already. If we have time for questions I will be happy to answer the odd one.

Q. Your figures on claims experience, are they with respect to North America?

A. That is North America and it's by a long shot not your industry. We are not just talking wind machines, although I have written a policy for wind machines for a wind farm group operating out of California. For example - telephone systems. Since MaBell was kicked out, there've been a whole bunch of people who came in. So, it is telephone systems. A tremendous variety of products. Large factories, machinery that sort of thing.

Q. Reed Stenhouse used to have an insurance warranty?

A. Insurance warranty - could be - but I don't know about it.

Q. Does the European experience push your prices higher or lower? What are the trends?

A. Overseas they've really not sold enough of it. That is the main criticism over there. If you look at the insurance business in North America particularly, the U.S. accounts for over 50 percent of the total dollars in insurance. If you are limiting your insurance to just the U.K., which was the originator of these two policies over there, you are limiting your market too much. I wrote a policy - it has to be almost 15 years ago - a product warranty thing on somebody manufacturing a new form of paper plant. What the policy did was cover the cost of converting to the old form if the new one didn't work. It was something like a $10,000,000 policy. A very large premium, about a quarter of a million dollar premium, I guess. The new plant just worked fine. So the underwriters were quite delighted with that.

Q. Do standards have a significant impact on premiums?

A. Absolutely. The insurance company.... I hate to say they are gambling, because if you take an insurance course they will give you all sorts of reasons why insurance is not gambling. When you come right down to it - insurance is gambling.... is betting that your product is better than their pricing, really. If you can prove - as automobile statistics do.... Actually, automobile statistics are about the only actuarial thing involved in casualty or liability underwriting because there is not enough database on anything else. There is only one industry that makes windmills. You get people that specialize in all sorts of things, they all have their own problems. Take the asbestosis situation, for example, where we are talking several billions of dollars in injuries. Who would have guessed that would have happened ten years ago when you were looking at a simple mine? But if anybody can come up with credible statistics, show them to an insurance company and say "Look, here is our track record. Here's how many breakdowns we have had. Here is how much these breakdowns have cost." That will have a meaning on how much premium the insurance company charges. Very simple, it is one of the advantages of an association. If you are together at a symposium like this, then you may want to get together and produce group statistics. It can be very, very valuable when you are going to buy cover like this on a group basis.

Q. I would then also assume that a company with a better track record would gain lower premiums?

A. Again, absolutely so. The policy on your class of thing was kind of an interesting thing that I found even in England. There is a policy that even guarranteed that your product would turn out the amount of kW's that you said it would turn out regardless of whether the wind blew or not. That is an interesting thing. That was sort of combining wind consultant with your manufacturer. He said, "The wind would blow 60% of the time here," and you said, "If it does, my machine will turn out 'x'". This policy guaranteed that both of you are right. Ok?

Q. It would seem then that it would be very much to the industry's advantage to start to collect the data that would substantiate their track record. I remember back in Woody Stoddard's comment about some of the windfarms in the United States having a hundred units and only five of them are operating at the present time. Would you not want to....

A. That's right. The trouble is the insurance companies do some research on this and they may know that. You'd rather develop your own statistics and say, "O.K. - This guy is manufacturing good ones." The information I had for the one in California that I wrote, they had had some difficulties with the blades breaking. But they have been doing this for about three years, 4 years something like that. They did have statistics. They had breakdown statistics. They had put it down to mainly blades breaking and they had found a new way of manufacturing blades which "should" get rid of that. That was the basis on which the underwriter picked up the risk.

Thank you.

ELECTROLYTIC HYDROGEN: TECHNOLOGY AND ECONOMICS

A.F. HUFNAGL

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ELECTROLYTIC HYDROGEN: TECHNOLOGY AND ECONOMICS

A.F. HUFNAGL

ABSTRACT

Major development projects have been initiated in several countries with the objective of significantly reducing the cost of electrolytic hydrogen. Progress is being made in improving electrical efficiency and reducing the capital investment required per unit of hydrogen production capacity. Large programs in Europe, the United States, Canada and Japan are now moving toward engineering demonstration of improved equipment design and performance.

The major development programs will be reviewed, highlighting the objectives, technical approaches, and progress for the advancement of electrolytic hydrogen technology, as well as the implications for on-site generation of hydrogen.

INTRODUCTION

Hydrogen generated from alkaline water electrolysis accounts for less than 1% of the total hydrogen production demand with current demands primarily met from petroleum and natural gas feedstock and as a by-product from other electrochemical processes.

Traditionally, electrolytic hydrogen has included markets where high purity hydrogen with no trace of sulphur is required, such as hydrogenation of oils, and the manufacturing of semi-conductor materials. Also, electrolytic hydrogen has been the preferred form in many applications where requirements are relatively small and merchant hydrogen would be expensive. Examples are its use in float glass manufacturing, in the manufacture of television tubes, lamps, and synthetic jewels, in bright annealing of stainless steel, grain orientation of transformer steels, chemical synthesis and a myriad of other applications(1). Several very large electrolyser plants have been built at locations where electricity is readily available and cheap, such as at Aswan in Egypt, for the production of ammonia fertilizers.

INTRODUCTION (Continued)

The recent dramatic cost increase of petroleum based products as well as the increased awareness of depleting fossil resources has served to promote development of more efficient electrolysers for new potential expansion of the electrolytic hydrogen market. Many proposals have also been made for hydrogen use as a medium in energy supply and storage, such as utilization of off-peak nuclear power, supplement of pipeline gas with hydrogen produced from under utilized hydroelectric power and, ultimately, in transportation, heating and all other applications where hydrocarbon fuels are being used.

Although water electrolysis is already a well established industrial method for hydrogen production, it has been widely recognized that reduced capital cost and improved energy efficiency will be necessary to meet new demands(2). Different approaches are being explored all over the world through active research and development, to improve and optimize electrolysis systems and to design new advanced cell modules.

In this presentation, the technological approaches, design criteria and operating requirements are reviewed as well as an outline on the status of development work in progress.

ELECTROLYSER TECHNOLOGY

From a historical viewpoint, the first application of water electrolysis in industry was based on the unipolar or tank type design which was made available at the turn of the century, while development of the first bipolar filter press type cell followed shortly after(3.4). International Electrolytic Plant Co. Ltd., installed the first Knowles unipolar cell plant in 1912 and by 1927 Norsk Hydro erected one of the first large electrolyser plants for the production of ammonia fertilizers. The first large electrolyser plant in North America was installed in Trial, British Columbia by Cominco (5) and by 1945 many large electrolysers were manufactured and installed throughout the world; the largest of which included the De Nora installation in Nangal, India, the Norsk Hydro installation in Norway, and the Demag installation in Egypt at the Aswan Dam. In 1955, Lurgi/Lonza made available the first large high pressure electrolyser systems.

The unipolar or tank-type design is characterized by each electrode having the same polarity on both surfaces and carrying out a single electrochemical reaction, i.e. either oxygen or hydrogen evolution at an anode or cathode respectively. A single unipolar cell contains a number of electrodes with all electrodes of the same polarity connected in parallel. The result is that overall cell voltage is equivalent to that of one anode/cathode pair, or 1.7 to 2.0 V. Alternate electrodes, generally anodes, are surrounded by diaphragms, which are impermeable to the passage of gas from the anolyte and catholyte compartments, but permeable to the cell electrolyte. Internal insulation is relatively simple at the low voltages, and high total currents per cell can be carried by increasing the number of electrodes in the cell tank. A sufficient number of cells can then be connected electrically in series by external copper bus bars to form a cell battery to produce the required hydrogen output demand.

Electrolysers of the bipolar design, on the other hand, consist of a massive assembly of a relatively large number of electrodes, each of which is cathodic on one side and anodic on the other side. The assembly is held together by a number of heavy longitudinal tie bolts in a manner similar to that of the plate and frame filter press. Each electrode is insulated from and electrically in series with its neighbour, with each pair of electrodes and separating diaphragm forming an individual cell unit. The direction of current flow is from one end of the cell stack to the other. A bipolar electrolyser may thus contain from thirty to several hundred individual cells in series at 1.7 to 2.0 V each, so that the corresponding applied voltage ranges from 50 to 600 V D.C. depending on required output capacity.

The major design difference between unipolar and bipolar relate to connection of elementary cells in series. In the unipolar design, there is inherent, a resistance loss in the terminals and intercell bus bar connections which is greater than that of the corresponding intercell resistance loss in bipolar cells. However, each cell in the bipolar assembly must be sealed against leakage of electrolyte by large external tie bolts, and must be insulated from one another to prevent short circuits. Also, gas/liquid slurry must be passed from each cell to a common header for gas-liquid separation with electrolyte recirculated to each individual cell through parallel channels. Thus, auxiliary equipment such as pumps, filters, heat exchangers and gas-liquid separation equipment are necessary for the systems operation, and design consideration of piping size must be taken into account to minimize bypass current which result between intercell plates. These bypass currents increase sharply with increasing number of cell units and have a bearing on current efficiency (i.e. gas production rate) as well as materials corrosion.

All of these factors imply relatively high capital costs and/or susceptibility to operating problem in large bipolar units. However, their greater capital costs are compensated for by operating at higher current densities (producing more hydrogen per area of electrode) with virtually the same operating voltage as the unipolar unit.

DESIGN AND OPERATING CONSTRAINTS

The operating cell voltage of an electrolyser can be regarded as having three major components; the reversible cell potential, the electrode overvoltages, and the voltage contributions due to ohmic losses in the electrolyte and electrodes. A breakdown of these components as a function of current density is presented in Figure 1 for a unipolar cell operating at 70°C and 25% KOH.

Presently, commercial cells operate at relatively low current densities ranging from 100 to 200 mA/cm^2. The operating current density is the most important single parameter in the operation of the cell that has a direct bearing on the voltage, hence operating cost, as well as the capital investment. Figure 2 illustrates typical performance curves for commercial bipolar and unipolar (Electrolyser) cells, along with projected performance levels for fuel cell type electrolysers such as General Electric's SPE technology. Although operating voltages are higher for unipolar design at any given current density, lower initial capital costs result in approximately equal overall costs where each is applied at its optimum economic current density as shown in Figure 3 selected to minimize total hydrogen cost.

Since conventional electrolysers operating at low current density ranges are not economically favourable for large scale industrial use, due mainly to relatively high capital investment, maximization of the operating current with simultaneous reduction in cell voltage (i.e. increased electrical efficiency) will make the electrolytic route economically more favourable. To this extent, cell voltage can be reduced, and thus efficiency increased by:

(i) Development of catalyst activation for electrodes.
(ii) Increase of the operating temperature from 70° to 90°C to 120°-200°C.
(iii) Modification of the electrolyser design to reduce ohmic losses.

The electrode overvoltages are the major contributors to electrical inefficiency in the absence of electrode activation. Suitable catalyst activation is needed to improve efficiency while increasing current density and most commercial electrolyser manufacturers have now developed activation systems and an increasing number of these are becoming known. Among some of the more promising materials, nickel cobalt spinel, perovskite ($La_{0.5} Sr_{0.5} CoO_3$) and plasma sprayed alloys of nickel and cobalt with stainless steel have been identified and tested for anode activation, while cathode activation materials include nickel boride, Teflon bonded nickel - cobalt thiospinel, and plasma sprayed nickel-aluminum(6). Important parameters in selection will be application cost, degree of voltage benefit, and stability with time.

The effect of increasing temperature for reducing cell voltages results in reduced reversible potential as well as overvoltage and electrolyte ohmic loss reductions. The benefits obtained though must be evaluated against increased corrosion rates of electrodes and diaphragm stability. Traditionally, asbestos woven clothes, papers and cardboards have been used in alkaline electrolysers as the separating diaphragm. Increase of the temperature above 100°C makes this material unsuitable and various inorganic and organic alternatives to asbestos are being tested (7). Inorganic materials that appear to be the most

DESIGN AND OPERATING CONSTRAINTS (Continued)

promising alternatives include polyantimonic acid, potassium titanate and silicate stabilized asbestos while organic diaphgragms fabricated from polysulfone (Udel), polyphenylene sulfide (Ryton) and Teflon are promising. However, extensive testing of long term performance of all materials is still required.

Reduction of ohmic losses through electrolyser design has more significance with unipolar designs than with bipolar and consideration must be given to reducing the gap between electrodes and minimizing the intercell bus bar losses.

Finally, although a number of advantages can be gained from operating an electrolyser at higher pressures (i.e. reduction in power consumption, delivery of gas at pressure, reduced cell size), the net gain in efficiency is generally offset by increases in cost for pressure vessel structures.

DEVELOPMENT PROGRAMS AND STATUS

The next generation of advanced technologies which it is felt will meet the future demand fall into three categories: high temperature - high pressure alkaline electrolysis, SPE electrolysis, and vapour phase electrolysis.

SPE ELECTROLYSIS

Much attention has been given to the new technologies which evolved during the 1960's with the U.S. aerospace program. Of these, General Electric's solid polymer electrolyte (SPE) technology is presently being developed under a joint government/industry program(8). The SPE technology is characterized by a thin solid plastic sheet of perfluorinated sulfonic acid polymer (Nafion). When a thin sheet of this material is saturated with water, it is an excellent ionic conductor providing low electrical resistance. Used in an electrolysis cell, it is the only electrolyte required with ionic conductivity provided by the mobility of the hydrated hydrogen ions passing through the sheet from one sulfonic acid group to another.

SPE ELECTROLYSIS (Continued)

The basic construction of an SPE cell is that of a bipolar stack, with each cell consisting of molded carbon current collectors (titanium covered on the anode side), the Nafion separator, and the anode and cathode electrode films. The Nafion separator also acts to seal and provides insulation between the current collectors. Operation of the cell requires recirculation of feed water to the anolyte compartment at a rate 70 times the stoichiometric amount required to produce hydrogen and oxygen. At the anode, oxygen is produced and carried with the water flow, while protonized hydrogen is carried through the SPE membrane to the cathode side along with 8 times the stoichiometric amount of water. The electrolyte sheet can withstand pressure differences up to 1000 psi, however, loss in current efficiency can result from back diffusion of product gas through the thin SPE membrane as a result of high differential pressure and is strongly dependent on operating temperature.

The overall goals of the SPE program are for development of electrolysers with a system efficiency of 85% (corresponding to an energy efficiency of 4.2 kWH/Nm^3 hydrogen production) and capital cost (battery limit) of $300 - 400 U.S./kW (1983 figures). Projections as to the cost and performance have been subject to numerous re-evaluations. Performance has been compromised by back diffusion and since the membrane is highly acidic, severe constraints on acceptable catalysts and current collector materials exist. Future cost projections are dependent on reduced catalyst loadings and use of cost effective materials.

VAPOUR PHASE ELECTROLYSIS

A hydrogen technology group at Dornier Systems in Germany is developing a system for the production of hydrogen from water by means of steam phase electrolysis at 900°-1000°C. Substantial reduction in the operating voltage is obtained at these temperatures (approximately 1.3V at 1000°C). The system was initially developed to operate in conjunction with a high temperature reactor which could supply superheated steam as a byproduct. More recent proposals suggest using lower temperature steam over 200°C.

VAPOUR PHASE ELECTROLYSIS (Continued)

The goal of the vapour phase concept at an operating temperature of 1000°C is for a capital cost of \$400 U.S./kW with power consumption of 3.1 kWh/Nm^3. Although vapour phase electrolysis appears to be a promising possibility for development of commercial equipment producing much lower hydrogen costs than advanced alkaline and SPE technology, its impact is much further into the future and more development work will be necessary before this route becomes a reality.

ADVANCED ALKALINE ELECTROLYSIS

Numerous development programs have been underway for several years to advance the state of technology of alkaline electrolysis to meet the near term requirements. The International Energy Agency (IEA) was formed in 1974 and includes member nations from countries in Europe (excluding France), North America and Japan. The main goals of the programs are selection and evaluation of electrocatalyst materials and separator materials for high temperature operation, and long term testing in commercial equipment. In Japan, a separate technological development program commenced in 1974 to solve problems of energy shortage. The "Sunshine Project" as it has been defined, has as its objective the development of high temperature and high pressure electrolysers for the storage of off-peak electricity in the form of hydrogen gas. A French program is being promoted by Electricite-de France in anticipation of availability of off-peak nuclear electricity by 1985. It is projected 40% of France's electricity will be produced by nuclear stations by 1985 and 65% by 1990. EdF will purchase advanced electrolysers and produce hydrogen for sale to industry. The price of electricity used in EdF's cost evaluations for internal generation is approximately one third the present industrial rate.

The basic guide lines for essentially all alkaline electrolyser programs are similar and development of electrolysers are being designed for operation at higher current densities of 100 mA/cm^2, operating temperature ranges of

ADVANCED ALKALINE ELECTROLYSIS (Continued)

120°-200°C and pressures of 20 to 50 atmospheres. Performance objectives of 90% efficiency (4 kWh/Nm³ hydrogen produced and capital costs similar to SPE technology is being anticipated. Major pilot plants have been started up or are in the construction stage ranging in size from 5 kW to 100 kW, for fundamental testing and evaluation of advanced designs.

Although the bipolar design has been universally accepted as offering the most potential for incorporation of advanced technology, more recent development through a joint research and development program between The Electrolyser Corporation Ltd. and Noranda Mines Ltd., has established modern unipolar electrolysers to be as advanced and competitive to bipolar equipment(9).

Two generations of advanced design have been developed, each offering significant improvements in energy efficiency and reduced capital cost. Increased energy efficiency for Generation I (1981) has been gained by use of new electrode activation techniques, reducing substantially the overvoltage contribution of cell voltage. Long term test results have established efficiency greater than 80%, typically 4.4 kWh/Nm³ H_2.

The second generation of advanced unipolar technology (1983) incorporates design modification which further reduce the ohmic resistance factor of the unipolar cells by approximately 50%, and improved energy efficiency of 85% or 4.2 kWh/Nm³ H_2 has been demonstrated in pilot plant tests. Figure 4 illustrates the performance improvements for these advanced unipolar designs in comparison to present industrial bipolar and projected SPE technology.

These new designs will allow for efficient operation at higher current densities to reduce capital cost as well. The optimum design current density for Generation I is 250 mA/cm² resulting in a 25% reduction in capital cost while the optimum current density for Generation II is 400 to 500 mA/cm² with a further cost reduction of 30%. The net cost of hydrogen produced is significant and advanced unipolar technology is expected to be as competitive as the projected SPE technology (Figure 5).

ADVANCED ALKALINE ELECTROLYSIS (Continued)

At the present state of development, large 100 kA Generation I cells have been fabricated and installed in an 600 kW experimental plant in Varennes, Quebec for long term testing and demonstration, while a 60 kW prototype unit based on the Generation II design has been in operation for a period of over a year.

CONCLUSIONS

The new markets for electrolytic hydrogen will require new advances in generating equipment, optimized for production of much larger gas outputs at reduced capital cost levels, and maximized for energy efficiency. The present development programs which have been reviewed, as well as others which have not been covered, are all striving to meet these demands for large scale electrolytic production as a chemical feedstock and eventually as a form of alternative energy.

The present primary markets for electrolytic hydrogen though will still be in the speciality gas applications, and the spin off benefits from these new developments will maintain electrolytic production as a economically viable option. Industries presently buying merchant hydrogen will find it more economical to produce gas on-site rather than lease or buy bulk storage equipment and pay the ever increasing demurrage, delivery and gas costs. Also, companies reforming natural gas or dissociating ammonia will find new electrolysis equipment more competitive as the price of natural gas increases and/or becomes less available.

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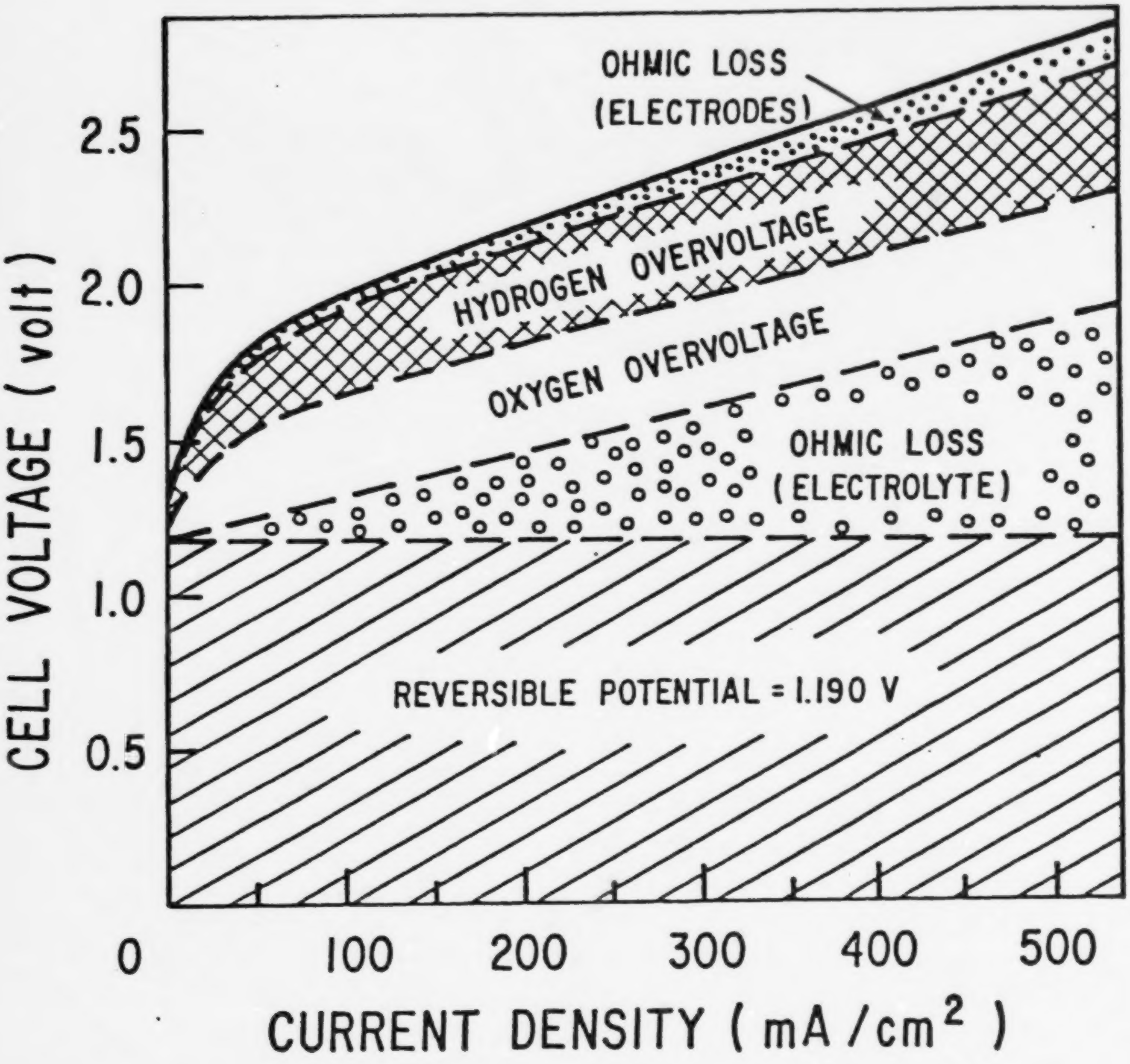

FIG. 1: VOLTAGE - CURRENT DENSITY PERFORMANCE OF AN UNACTIVATED UNIPOLAR ELECTROLYSER

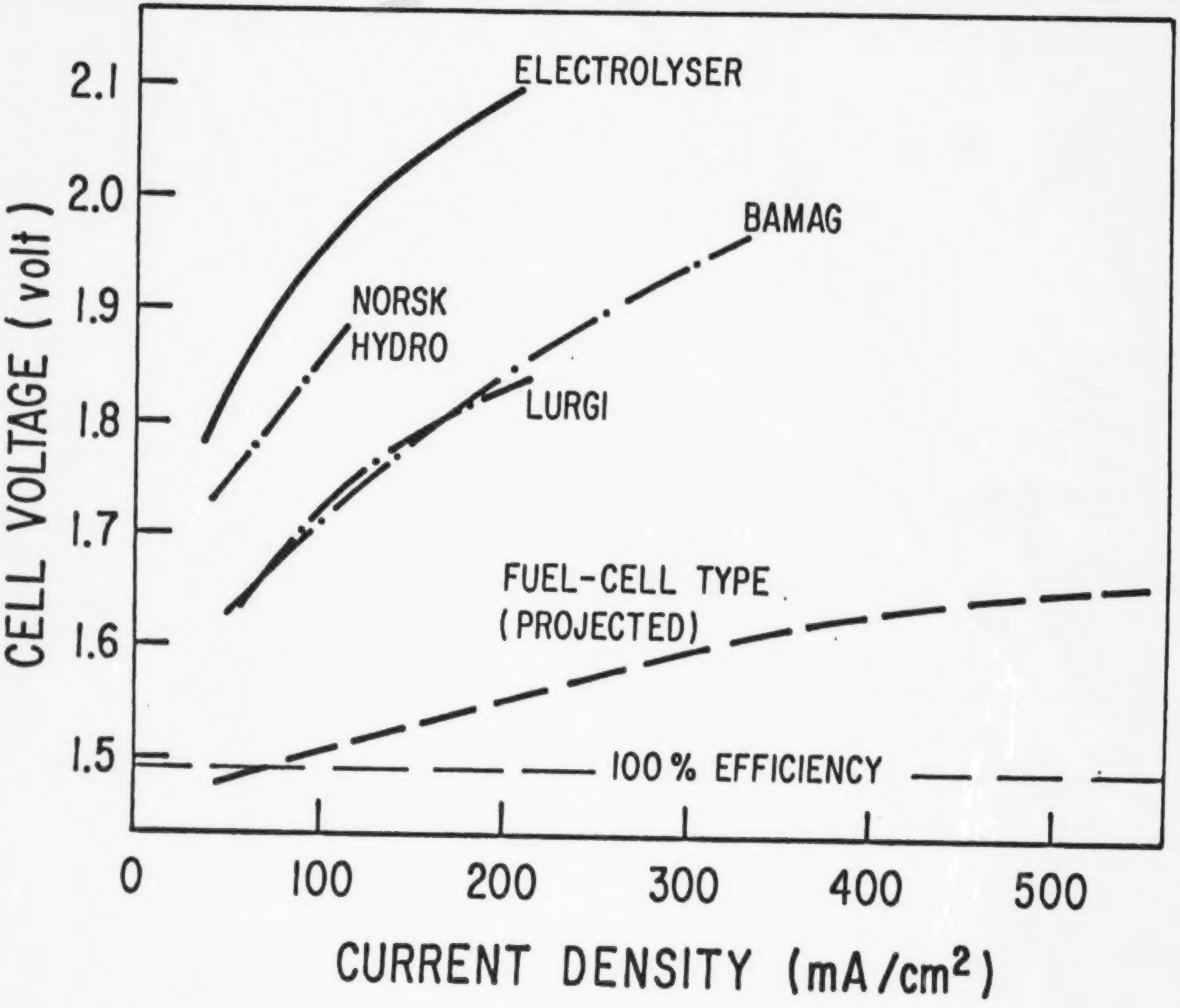

FIG. 2: VOLTAGE - CURRENT DENSITY PERFORMANCE OF DIFFERENT ELECTROLYSER TECHNOLOGIES

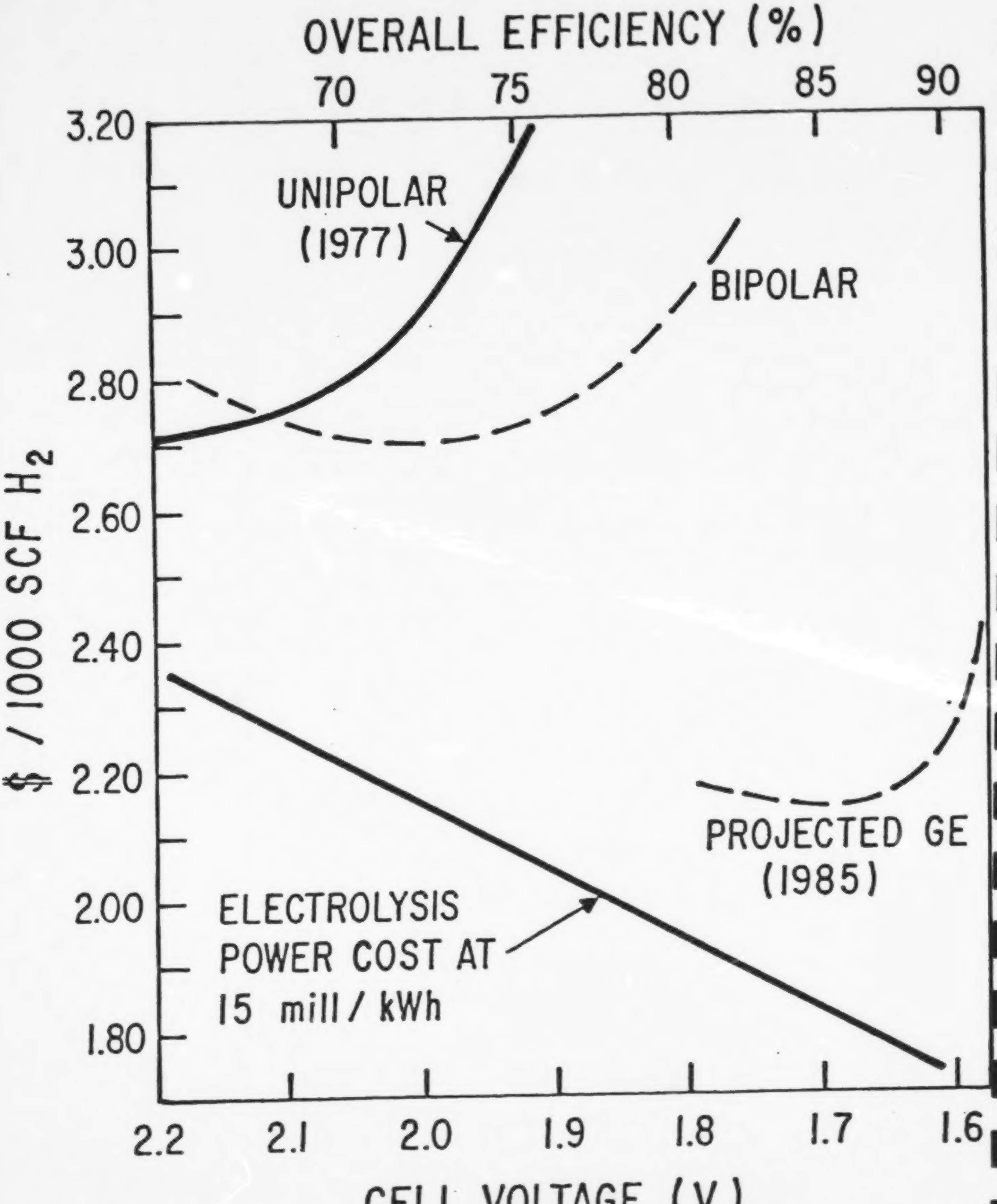

FIG. 3: TOTAL COST OF HYDROGEN FOR VARIOUS ELECTROLYSER TECHNOLOGIES AS A FUNCTION OF CELL VOLTAGE

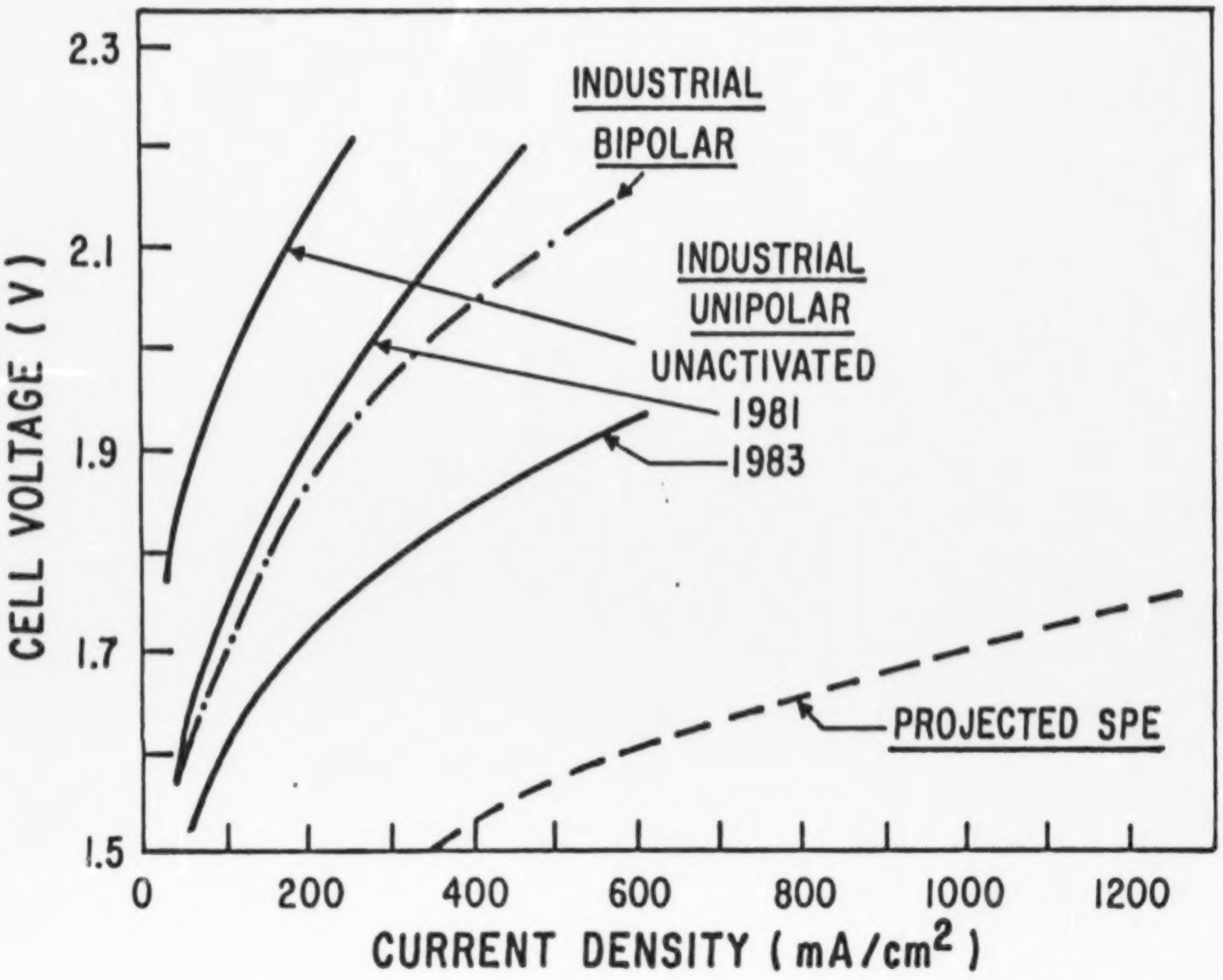

FIG. 4: PROJECTED VOLTAGE - CURRENT DENSITY PERFORMANCE LEVELS OF ADVANCED UNIPOLAR ELECTROLYSERS IN COMPARISON TO BIPOLAR AND SPE TECHNOLOGY

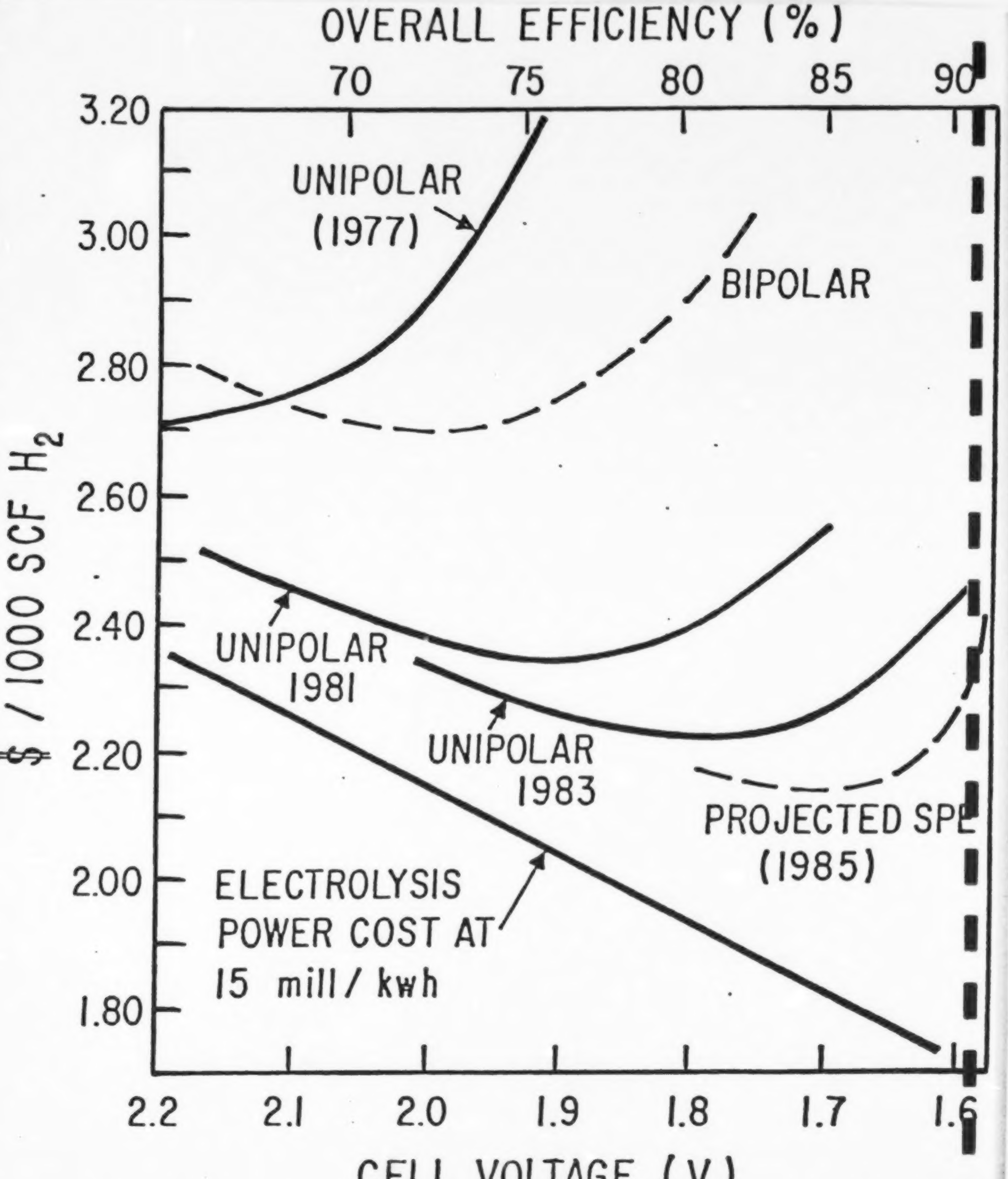

FIG. 5: PROJECTED TOTAL COST OF HYDROGEN FOR ADVANCED UNIPOLAR ELECTROLYSERS

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